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GROUND WATER--MINERALOGY RELATIONSHIP FOR IN SITU OIL SHALE RETORTING

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Potential ground water problems associated with Modified In Situ (MIS) oil shale retorting need to be examined in order to minimize or mitigate possible invasion of spent shale leachates into ground water systems in actively mined or mined and abandoned sites. This background report on the hydrology, mineralogy, and ground water chemistry of the Green River Formation of the Piceance Basin has been compiled in order to provide a comprehensive document on what is known about the three physico-chemical systems which will interact to produce ground-water quality variations at an uncontrolled mine site in the Piceance Basin and more specifically, at either of two federal lease tracts, Ca and Cb, situated therein

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FOREWARD

EPA is charged by Congress to protect the Nation's land, air, and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise, and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life. In partial response to these mandates, the Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, is charged with the mission to manage research programs: to investigate the nature, transport, fate, and management of pollutants in ground water; to develop and demonstrate technologies for treating wastewater with soils and other natural systems; to control pollution from irrigated crop and animal production agricultural activities; and to develop and demonstrate cost-effective land treatment systems for the environmentally safe disposal of solid and hazardous wastes.

The purpose of this project was to provide a state-of-knowledge document on the hydrology, mineralogy and ground water chemistry of the Green River Formation in the Piceance Basin. It has been compiled to provide a comprehensive document on what is known about the three physico-chemical systems which will interact to produce ground-water quality variations associated with in situ oil shale retorting operations. Beginning with this information, detailed projects addressing specific ground water problems can be formulated.

Clinton W. Hall

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PREFACE

Since the recent emphasis on underground rather than surface retorting of oil shale began, it has been apparent that potential groundwater problems would need to be examined in order to minimize or mitigate possible invasion of spent shale leachates into groundwater reservoirs in actively mined or mined and abandoned sites. The following background report on the hydrology, mineralogy and groundwater chemistry of the Green River Formation in the Piceance Basin has been compiled in order to provide a comprehensive document on what is known about the three physico-chemical systems which will interact to produce groundwater contamination at an uncontrolled mine site in the Piceanace Basin and more specifically, at either of the two federal lease tracts situated therein.

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INTRODUCTION

The Green River Formation underlies an area of approximately 6,500 square kilometers (17,000 square miles) in Wyoming, Utah, and Colorado, (Figure 1), and contains an estimated 1.8 trillion barrels of oil in shale beds (Culbertson and Pitman, 1973, p. 500). Structurally, it occurs in seven basins - the Uinta, Piceance, Sand Wash, Washakie, Green River, Great Divide, and Fossil basins. Stratigraphically, the formation generally thickens towards basin centers, and laterally inter-tongues and is interbedded with adjacent units towards basin margins. Sedimentologically, it represents deposits of two large Eocene lakes, Gosiute and Uinta, in which oil-bearing shales associated with beds of tuff, siltstone, claystone, sandstone, halite, trona and nahcolite were deposited. In total thickness, it may exceed a few thousand meters (Donnell, 1961), and in places it is saturated by ground water throughout its entirety.

Recently, the modified in situ process of extraction of oil from Green River shales has received much attention as a potential method of retorting (Gary, 1979). The MIS method is advantageous because shale extraction costs are reduced, deeper shale beds can be retorted, less water is required, and less surface disturbance occurs from spent shale and retorting processes (see Gary, 1979 for references). However, the dewatering of the mining zone and the chemical and mineralogic alteration of it during in situ retorting will change the local ground water regime.

Alteration of ground water flow rates and volumes, and changes in ground water chemistry will certainly result from an MIS burn. In addition, changes in local mineralogy will occur, dependent upon changes in quantities, rates and directions of water moving through the MIS system. A new equilibrium of ground water quality will be established after retorting. Accordingly, the purposes of this report are: 1) to review the existing knowledge regarding the potential effects of the MIS process on properties of ground water storage and flow in the Green River Formation, 2) to review the existing knowledge of the mineralogy of the Green River Formation, and 3) to review the existing knowledge of possible mineral-ground water interactions during and after an MIS event.

SECTION 1
HYDROLOGY

GENERAL

The modified in situ process (MIS) is potentially an important method of retorting oil shale in the Green River Formation in Wyoming, Utah, and Colorado. In this method, from 20% to 40% of the oil shale is mined by conventional methods and retorted at the surface. The remainder is processed underground by combustion drive methods after being rubbilized in place by explosion (Slawson and Yen, 1979, p. 37-39). Consequently, the MIS process will result in alterations of the ground water regime different from those obtained from traditional underground mining and surface retorting processes. Specifically, changes in the types and distributions of permeability and thus the rates and volumes of flow will result. These changes, together with the altered chemical and mineralogic composition of the mining zone, will in turn affect the final chemical quality of ground water.

Although investigations have been made of the chemical and flow properties of ground water in the oil shale basins, a thorough assessment of the effects of the modified in situ process has not been accomplished, principally because of its quite recent development as an important process. However, it is apparent that underground changes in mineralogy and water chemistry will be fewer for standard methods as compared to the modified in situ process.

Existing models of oil shale basins and their ground water systems are regional in scope and emphasize dewatering rates and effects of underground mining processes. Such models, constructed and calibrated for the hydraulics of intergranular permeability, may apply over large areas, but are not the best predictors of the local effects of changes from initial conditions of secondary (fracture and/or solution) permeability to rubbilized intergranular permeability, as will occur during the MIS retort process. And finally, no models in existence consider ground water quality equilibria and their responses to mining in conjunction flow properties in the oil shale environment. Models including processes of hydrodynamic dispersion and hydrogeochemical attenuation in fracture flow systems are applicable in solving these problems.

Because approximately two-thirds of the oil shale potential of the Green River Formation exists in the Piceance basin in Colorado (Culbertson and Pitman, 1973), and because initial steps are underway to recover oil using the MIS process at both federal lease tracts C_a and C_b, these areas will be emphasized.

PREVIOUS INVESTIGATIONS

Since 1874 when the Green River group was recognized by one of the Hayden Surveys (Peale, 1876), hundreds of studies and reports have been completed regarding its lithology, structure, mineralogy, and oil shale potential (see USGS Circular 754 for a recently compiled list of 895 references). However, only since 1964 has water been emphasized in investigations of the resources of the Green River oil shale area, and especially since the issuance of the Colorado and Utah Federal Lease Tracts, the number of investigations related to ground water in oil shale has increased. Notable among these are water reports by the U.S. Geological Survey, various state agencies, and the tract lease holders and their consultants (Mullens, 1977).

GEOLOGIC COMPARISON OF OIL SHALE BASINS

The Green River Formation exhibits more similarities than differences throughout the oil shale basins.

A stratigraphic and sedimentologic comparison of the basins (Figure 2), clearly illustrates the spatial and temporal aspects of regional stratigraphy in the restricted lacustrine environment of oil shale deposition. As expected, the fluvial and fresh-water lacustrine deposits generally coincide with basin margins. Likewise, saline deposits, and especially evaporites, occur as isolated units near the centers of the basins. Principal minerals in oil shale are quartz, dolomite, sodium feldspar, potassium feldspar, illite, nahcolite, dawsonite, calcite, and analcime (Robb and Smith, 1974).

Notable differences in geology do exist, however. In the Uinta basin, the oil shale sequence is thinner, it contains less oil, and there are fewer saline minerals than in the Piceance basin (Murray, 1974; Cashion, 1967; Ritzma and Seeley, 1969). In the Wyoming basins (Figure 1), the oil shale beds (principally in the Wilkins Peak, Tipton shale, and Laney Members) are widespread, thin, and lean in oil compared to the Piceance basin units (Roehler, 1969; Bradley, 1931; Culbertson, 1969). The Wyoming deposits contain significant amounts of trona and halite, but usually not at localities that are also rich in oil.

Probably the basin that is stratigraphically and structurally most representative of the processes and geology of Green River oil shale deposition is the Piceance basin (Figures 1 and 2). The Green River basin contains all the important sedimentologic elements found in the other basins, but the Piceance basin units are thicker, cover a smaller area, and contain significantly more oil shale.

GROUND WATER IN THE GREEN RIVER FORMATION

Ground water investigations have been done to some extent in each of the oil shale basins, but in detail and scope they vary widely. As part of the environmental investigations for the Federal Lease Tracts in the Uinta and Piceance Basins, quantitative information on groundwater flows, storage, and quality were collected by the tract leaseholders and governmental agencies (for examples, Tipton and Kalmbach, 1977; White River Shale Project, 1976). The state of Utah has recently published valuable information on the Uinta Basin (Hood, 1976; Hood and Fields, 1978; Price and Miller, 1975). Hydrologic atlases containing reconnaissance information on the oil shale basins in Wyoming were done by Welder (1968) and Welder and McGreevy (1966). However, the groundwater resources of the Piceance Basin have received the most emphasis (for examples, Coffin, Welder and Glanzman, 1971; Weeks et al., 1974; Boettcher, 1972; Murray, 1974; Weeks, 1978). In cooperation with the state of Colorado and the tract leaseholders, the U.S. Geological Survey is currently expanding and refining its digital model of the Piceance Basin groundwater system. It also maintains a hydrologic monitoring network of wells, springs, and streams in the area (Ficke, 1974; Weeks, 1978; Welder and Saulnier; 1978).

GROUNDWATER IN THE UINTA BASIN

The groundwater in the oil shale of the Uinta Basin has been studied regionally by the U.S. Geological Survey in cooperation with the state of Utah (Price and Miller, 1975; Hood and Fields, 1978; Hood, 1976), and locally by the federal leaseholder (White River Shale Project, 1976), at tracts U_a and U_b.

The Green River formation was not included by Hood (1976) as one of fifteen formations of water-bearing significance in the Uinta Basin. He reported (p.9) "very low to low" permeability for the formation, with transmissivities of 0.08 to 0.22 m^2/day (0.9 to 2.4 ft^2/day, Weir, 1970). Water quality is likewise poor, commonly from saline to briny.

At tracts U_a and U_b, the limited data available on aquifer characteristics are from only four wells. The only significant aquifer at the tracts, the Bird's Nest aquifer, lies approximately 125 meters above the top of the Mahogany zone and is approximately 40 meters thick. It dips to the northwest at a gradient of approximately 0.20. Available aquifer coefficients are not satisfactory for making generalizations concerning the quantity or rate of groundwater movement at the tracts. However, limited pumping tests involving four wells provided transmissivities of the Bird's Nest aquifer from 930 m^2/day (10,050 ft^2/day) to 0.19 m^2/day (2.01 ft^2/day) and storage coefficients from 0.10 to 3.5×10^{-4} (White River Shale Project, 1976). Clearly, more quantitative aquifer testing is necessary before substantive conclusions can be drawn.

Other Basins

The oil shale areas in Wyoming offered for federal lease did not receive successful bids; consequently, no development of oil shale has begun there. Very general, regional information on groundwater was provided by Welder (1968), and Welder and McGreevey (1966). However, the Laramie Energy Research Center is conducting experiments on oil shale retorting at their facility near Rock Springs; this information should be valuable in comparison to that from the Piceance and Uinta Basins.

GROUNDWATER IN THE PICEANCE BASIN

The richest oil shale in the Piceance Basin (Figures 3-7) is in a layer known as the Mahogany zone. In much of the Piceance Basin it is an aquitard (Figure 5), restricting the vertical movement of groundwater. The U.S. Geological Survey recognizes two major aquifer systems, one above and another below the Mahogany zone (Weeks, 1974). The upper aquifer includes the Uinta Formation (formerly called the Evacuation Creek member), and the upper strata of the Parachute Creek member of the Green River Formation, consisting chiefly of oil shale. The lower aquifer is the section of the Parachute Creek member below the Mahogany zone. It may or may not include a high resistivity zone (designation varies in different reports) of normally low permeability. The Garden Gulch and Douglas Creek members, beneath the Parachute Creek member, are like the Wasatch formation below them. They all consist of clay, shale, and lenticular sandstone beds (Figure 4).

Units below the Parachute Creek member are not aquifers in the Piceance Basin. Some alluvial deposits along stream channels are aquifers, but will be affected only indirectly by MIS retorting; thus they will not be considered here.

As of 1979, over 100 exploration or groundwater sampling, testing and/or monitor wells had been drilled in the Piceance Basin (Figures 8-11). Approximately 30 wells exist at each Federal lease tract, with nearly as many additional wells nearby (Figures 9 & 11). Many of the exploration wells were drilled through both aquifers and still permit the exchange of water between them. However, programs of well recompletion for testing and/or monitoring some wells have recently been initiated.

The detailed testing of aquifers at Tracts C-a and C-b have resulted in the identification of three aquifers at Tract C-b and two at Tract C-a, different from those identified by the U.S.G.S. (Figures 6-8).

Lower Aquifer

The major individual bedrock aquifer in the Piceance Basin is the lower aquifer (leached or low resistivity zone (Figure 7). Primarily, it has secondary permeability, like that of both the Mahogany zone and the upper aquifer. In addition, its fracture permeability has been enhanced by the solution of nahcolite and other minerals. Its transmissibility is highly variable and may reach 250 m^2/day (2700 ft^2/day, Coffin, Welden, and Glanzman, 1971, Rio Blanco Oil Shale Project, 1977). In contrast, during pumping tests of individual horizons in the lower aquifer at Tract C-b, low transmissibilities from 0.15 to 8.5 m^2/day (1.6 to 92 ft^2/day) were obtained (Figure 11) (C-b Venture, 1976). Storage coefficients of the lower aquifer in such tests have ranged from 10^{-3} to 10^{-7}.

The variation in transmissibility is a result of the pronounced anisotropy of permeability of the aquifer, which is primarily due to the orientation of fracture systems (both faults and joints) and variations between different oil shale beds. In addition, the preferred orientation of faults and folds, in northwest, southeast, west and east directions, undoubtedly has a significant effect on groundwater movement (Figure 10).

Upper Aquifer

The upper aquifer has chiefly fracture permeability, with little evidence of significant solution permeability (Weeks et al., 1974). Its transmissivity ranges up to approximately 9 m^2/day (1,000 ft^2/day) and generally increases from east to west in the basin. Most investigators have noted that hydraulic coefficients of the upper aquifer also vary widely within small distances. In general, however, the upper aquifer is less permeable than the lower. Of course, the upper aquifer is not confined everywhere in the basin. It will have to be dewatered to retort oil shale by the MIS process.

Groundwater Movement

Studies of wells penetrating both the upper and lower aquifers have shown distinctly different water levels between them. In general, potentiometric heads are higher for the upper aquifer in recharge areas and higher for the lower aquifer in discharge areas. Head differences commonly vary between 15 and 30 meters. The results indicate that the groundwater system is recharged at higher elevations near the basin margin on the south, and that discharge from the groundwater system to the streams occurs near the basin center and to the north along White and Yellow Creeks (Figure 5).

Mahogany Zone

To permit the recharge-discharge transfer of water in the manner shown in Figure 5, the Mahogany bed separating the two aquifers must be permeable enough to allow movement of water through it. Consequently, it is not totally a confining layer, but constitutes a leakance zone. Leakance values determined thus far from pumping tests have ranged from zero to 0.11 m/day (0.37 ft/day).

Tracts C-a and C-b

Although the Mahogany zone occurs everywhere in the basin, it does not everywhere separate the upper and lower aquifers in the same manner. At Tract C-b it is generally included as the top of the lower aquifer (Figure 7), while at Tract C-a, it is included as the bottom of the upper aquifer (Figure 8). At Tract C-a, the lower aquifer is approximately 500 feet below the Mahogany zone, near the Blue Marker (Rio Blanco Oil Shale Project, 1976). At Tract C-a, the upper aquifer has a higher potentiometric head than the lower, which is in direct contrast to the relationship at Tract C-b.

Prediction of the cones of depression that will result from dewatering Tracts C-a and C-b were made by the leaseholders using computer modeling techniques (C-b Shale Oil Venture, 1977; Rio Blanco Oil Shale Project, 1976; 1977). In addition, Tract C-b was studied by traditional methods employing the Jacob-Lohman constant drawdown method (Tipton and Kalmbach, 1977). The most realistic results probably are those for Tract C-a, in which the anisotropic character of the upper aquifer there and fault boundary conditions were considered (Figures 9 & 10). Dewatering of the upper aquifer at Tract C-a through the spring of 1980 produced significantly more water than anticipated but the shape of the cone of depression has followed predictions fairly closely (Glenn Miller, U.S.G.S. Oil Shale Supervisor's Office, Oral Communication). In contrast, the shape of the cone predicted for Tract C-b is circular (Figure 12). It is considered unlikely by most experts that the true cone will develop with a circular shape.

Aquifer tests to determine aquifer coefficients of thin zones constituting aquifers and aquitards have been done at both Tracts C-a and C-b (C-b Shale Oil Venture, 1976; Rio Blanco Oil Shale Project, 1977). Significant anisotropic properties were discovered at both tracts (Figures 9 & 11). Very low horizontal and vertical permeabilities were reported from the tests at Tract C-b, while higher permeabilities and more significant effects of fault boundary conditions were noted at Tract C-a. The basic data collection procedures and the data themselves have not been published, however, and none of the tests were correlated with aquifer mineralogy or hydrogeochemistry.

GEOLOGY OF TRACT C-a

Tract C-a is located within that portion of the Piceance Creek Basin in Northwestern Colorado which drains into the White River. The tract is located approximately 27 miles southwest of Meeker and encompasses approximately 8 square miles (5,090 acres), as shown in Figure 13.

The topography of Tract C-a is characterized by northeast-trending canyons and ridges. The slopes of the canyon walls are steep, the valley floors are narrow, and the ridges are broad and rounded. Altitude within the tract varies from 6,600 feet in Corral Gulch to 7,400 feet on the ridges near the southwest portion of the tract.

The principal drainages on and near the tract are Corral, Water, and Box Elder Gulches, and Dry Fork. All of these streams flow into Yellow Creek. All of the major streams, both on Tract C-a and in the surrounding vicinity, trend and flow northeast. The majority of streams are intermittent and flow only during the period of spring runoff and following locally heavy rains. Yellow Creek, which receives all the surface runoff from the tract, has a drainage area of approximately 258 square miles. Yellow Creek is intermittent near Tract C-a, but is perennial near its confluence with the White River.

The annual precipitation in the vicinity of Tract C-a varies from 12 to 24 inches. Just less than half of the precipitation occurs as snow from December to April. Spring precipitation is low. However, during the summer months, occasional thunderstorms with accompanying flash floods occur in this region (Rio Blanco Oil Shale Co., October 1974-February 1975).

Structure

The general region of the western Piceance Creek Basin containing Tract C-a is underlain by a system of alternating anticlines and synclines. Locally, the area encompassed by Tract C-a displays beds striking to the north and dipping to the east and northeast at 200-350 feet/mile (2-4°). One major anticline and three major fault systems are present within the tract along with four minor folds and multiple subsidiary faults (Figures 14 and 15).

The three major northwest-trending en echelon fault systems are present on the northeast flank of Sulfur Creek anticline. These consist of a series of grabens, downthrown crustal blocks bounded on either side by faults. The three grabens are parallel-subparallel to the Sulfur Creek anticlinal axis. The graben-bounding faults are all very high angle to nearly vertical (84°+) normal faults as observed at the surface. Fault displacements range from a few feet to as high as 237 feet. On Tract C-a this fault displacement observed at the surface diminishes with depth (Rio Blanco Oil Shale Co., September 1977).

In addition to the three grabens, multiple, subsidiary normal faults are present within Tract C-a. All are high angle to vertical and most have displacements of less than 50 feet at the surface. Very likely, displacements observed along these faults as well as the graben-bounding faults diminish with depth in the subsurface.

Analysis of joint orientation data within Tract C-a indicates a joint system consisting of three main sets. For the entire tract, the average orientation of each set is as follows:

1. The dominant set strikes N56° - 76°W with dips of 74° passing through vertical to 86°NE. The set essentially parallels the axis of the Sulfur Creek anticline and the three en echelon grabens.
2. The secondary set strikes N28°E with a dip of 80°NW.
3. The tertiary set strikes N15°W with a dip of 75°E (Rio Blanco Oil Shale Co., September 1977).

Stratigraphy

Figure 16 is a generalized stratigraphic column of Eocene rocks in the Piceance Creek Basin. Also shown are the stratigraphic positions of the main oil shale interval of the lower Parachute Creek member, the oil shale interval defined within Tract C-a and several key stratigraphic markers.

Figure 17 is a SW-NE stratigraphic cross section across Tract C-a, typically oriented to the depositional strike of the Parachute Creek member's main oil shale interval. It illustrates the stratigraphic positions of four key electric-log markers and two key lithologic markers which are persistent throughout most of the Piceance Creek Basin and are extremely useful in subsurface correlations. The electric-log markers are particularly useful because they are easily recognized without the benefit of Fischer assay data or lithologic descriptions.

The four electric-log markers are, in stratigraphically ascending order: the orange marker, blue marker, B-groove, and A-groove. All four are associated with low resistivity intervals which reflect low-grade oil shale zones. The orange marker is the base of a low resistivity interval and defines the lower stratigraphic limit of the richer oil shale zones in the upper part of the Douglas Creek - Garden Gulch members. The blue marker forms the top of a low resistivity interval and defines the contact of the Douglas Creek - Garden Gulch members with the overlying Parachute Creek member.

The A and B-grooves are two low resistivity units which define the top and bottom of the Mahogany zone, respectively. Their deepest inflections on resistivity logs (middle A-groove, middle B-groove) are consistent regional "log picks."

Within the Mahogany zone itself are two important lithologic markers. The Mahogany marker is an analcimized volcanic ash bed generally 2 to 6 inches thick occurring about 25 to 30 feet below the middle of the A-groove. About 15 feet below the Mahogany marker is a 2 to 4 foot thick interval of very high grade dark brown to black oil shale called the Mahogany bed. Figure 18 is a SW-NE structural-stratigraphic cross section extending basinward across Tract C-a. Included are the four persistent electric-log markers (Rio Blanco Oil Shale Co., September 1977).

The oil shale zonation established within Tract C-a (Figure 17) is based on one established by Cashion and Donnel (1972). The main oil shale interval of the Parachute Creek member is bounded at its top by the A-groove and at its base by the blue marker. Rio Blanco's zonation expands their zonation above and below the main oil shale interval resulting in 19 alternating rich and lean zones, 9 rich and 10 lean. These zones are designated L-00 through L-8 in stratigraphically ascending order. The Mahogany and A-groove (AG) zonal nomenclature is retained because of their well-established usage (Rio Blanco Oil Shale Co., September 1977). On Tract C-a the total oil shale zone averages 1,200 feet in thickness.

Tract History

On March 1, 1974, Gulf Oil Corporation and Standard Oil Company (Indiana) were awarded the lease for Colorado Lease Tract C-a. The two parent companies formed a general partnership in 1978, which was renamed the Rio Blanco Oil Shale Company. The sole purpose of the company is to develop Tract C-a (Rio Blanco Oil Shale Co., February 1981).

Total oil reserves on the tract are estimated to be nine billion barrels, of which two to five billion barrels can be recovered depending on the method used. The lease runs for 20 years after the effective date (March 1, 1974), or as long as there is commercial production from the tract, subject to readjustment of terms and conditions at 20-year intervals (Rio Blanco Oil Shale Co., February 1981).

One of the requirements of prototype oil shale leases is that a detailed development plan (DDP) be filed before the third anniversary date of the lease. The purpose of the DDP was to outline a program which showed that the tract would be developed in an orderly and diligent manner (Rio Blanco Oil Shale Co., February 1981).

At the time of the lease sale, Gulf and Standard, as well as the Department of Interior (DOI), expected the oil shale on Tract C-a to be mined from an open pit and retorted in surface retorts. The surface processing facilities as well as the initial disposal of the overburden and processed shale would be located off tract. This method was chosen because it was economically feasible and the entire tract could be mined to maximize recovery of the resource (Rio Blanco Oil Shale Co., February 1981).

Thus, in 1976, Gulf and Standard submitted plans for producing oil at 50,000 barrels-per-stream-day from shale mined from an open pit. The oil shale would be retorted aboveground. The pit was to be started in the northwest corner of the tract and would progress to the southeast. The overburden and processed shale was to be placed off-tract for the first 30 years, after which pit backfilling was to begin. The off-tract land required for the operations was approximately the same as the tract area. Figures 19 and 20 illustrate the proposed pit area and adjacent shale disposal lands (Rio Blanco Oil Shale Co., February 1981).

After Gulf and Standard acquired the lease, it was ruled that the Secretary of the Interior did not have the authority to grant additional Federal leases for surface uses such as disposal and processing facility siting. In addition, air quality monitoring in the area showed occasional violations of Federal standards. Since this was occurring without any industry in the area, Rio Blanco believed that an oil shale facility could not be built. As a result of these problems, a one-year lease suspension was granted from September 1, 1976 to September 1, 1977 (Rio Blanco Oil Shale Co., February 1981).

During this suspension the air quality policies were modified, allowing for some development on the tract. However, off-tract land for disposal was not available. Therefore, Rio Blanco reevaluated other available technologies and in May 1977 submitted a revised DDP. This plan proposed the development of Tract C-a using the modified in situ (MIS) technique combined with surface retorting of the shale mined and brought to the surface in connection with the MIS method (Rio Blanco Oil Shale Co., February 1981).

Included in this revised program was a ten-year Modular Development Phase (MDP) in which a series of MIS retorts are developed and burned in sequence. The purpose of this phase is to gain operating experience, improve process efficiency, confirm capital and operating costs for a commercial operation and ensure environmental integrity of the operations (Rio Blanco Oil Shale Co., February 1981).

Figure 21 shows the facilities and layout of the proposed MIS project. The configuration for the first three retorts is shown in Figure 22. Mining for creation of the retorts is required on only one level, G level. Sub-E level is required for dewatering. Figure 23 shows a more detailed cutaway view of Retort 1. Figure 24 shows three of the proposed retorts and their relationship to depth and aquifers.

Retort 0 was burned during the last quarter of 1980, and produced 1,750 barrels of shale oil during a 60 day test of the MIS method. Of this, 1,040 barrels of oil were collected as a liquid and the remainder produced as a vapor.

Currently, Retort 1 is in final preparation stages and will be burned during 1981. A third retort is also scheduled for later in 1981, to further test the feasibility of this method.

Rio Blanco has also been actively studying the environmental impacts which could result from development of Tract C-a. A two-year baseline study was completed in 1977, and included studies of meteorology and air quality, terrestrial and aquatic ecology, hydrology, interrelationships among components of the ecosystem, and areas of cultural resources. Since completion of the baseline environmental study, the parameters of the study continue to be monitored.

In February 1981, Rio Blanco requested a modification to their DDP. This appeal included the demonstration of a Lurgi-Ruhrgas surface retort during the MDP as well as a small open pit mine to provide feed shale to the retort. MIS development may not prove to be the best approach for commercial development of Tract C-a. Legislation to give the Secretary of the Interior the authority to make off-tract land available failed to pass in Congress in 1980, but is expected to be reintroduced during the 1981 session of Congress. Thus, an open pit mine with a surface retort demonstration unit would be valuable to evaluate. Whether Rio Blanco proceeds with an MIS or open pit commercial plan, surface retorting of oil shale is required for maximum conservation of the resources (Rio Blanco Oil Shale Co., February 1981).

Rio Blanco agreed with the Colorado Division of Wildlife to exchange 457 acres of state land north of and adjacent to Tract C-a for lands of equal value to be designated by the Department of Wildlife (Figure 25). Rio Blanco has all surface rights, including those for site preparation, construction and all other activities necessary for the Lurgi demonstration project. The development of this project includes a two-year demonstration period beginning in May 1981, and up to three years of operation of the 4,400-ton-per-day surface retort. The pilot plan for the Lurgi-Ruhrgas project development and operation is shown in Figure 26. The open pit configuration and geologic cross section of the northwest portion of Tract C-a are shown in Figures 27-29. Figure 30 shows Rio Blanco's current construction and operation schedule for Tract C-a (Rio Blanco Oil Shale Co., February 1981).

Aquifer Identification

Development activities on Tract C-a have led to the identification of four aquifers in the vicinity of the oil shale formations. These consist of alluvial aquifers, two deep bedrock aquifers, and the Douglas Creek sandstone aquifer. The only aquifers of significant concern in the commercial development of the oil shale resources underlying the tract are the two bedrock aquifers. These have been designated the upper aquifer and lower aquifer.

These two aquifers have been separated on the basis of differences in water quality, water temperature, water yield, and permeability. The positions of the aquifer boundaries were established by the analysis of wate production records made during the drilling of boreholes; temperature and fracture descriptions of the core samples; and temperature and flowmeter logs.

The upper aquifer, as shown in Figures 31 and 32, is an identified water-bearing zone of similar water quality and temperature characteristics with an upper stratigraphic limit above the Mahogany zone and a lower limit below the B-groove around the R-5 zone. The interval traditionally called the upper aquifer is really two water-bearing zones, one above and one below the Mahogany zone. From recent observations of water-producing zones made during shaft sinking, the Mahogany zone actually has a very low vertical permeability (15×10^{-7} ft/day). It is actually an aquitard, confining a water-bearing zone associated with the A-groove above it and a water-bearing zone associated with the B-groove below it (Cindy Sunblad, Tract C-a, Personal Comm., 1981) (Figure 33).

The majority of upper aquifer monitoring and hydrologic testing on Tract C-a has been performed in wells which are completed within the entire aquifer as it is traditionally defined. Thus, available data represent the hydraulic properties of a composite aquifer which contains the A-groove water-bearing zone, the B-groove water-bearing zone, and the Mahogany zone aquitard. Further hydrologic evaluation will be required to delineate the specific properties of the components of the upper aquifer (Rio Blanco Oil Shale Co., February 1981).

The aquifer occurs in the fractured oil shale and marlstone. The primary porosity of these formations was very low, but subsequent fracturing and dissolution vugs have resulted in high secondary porosities. The upper aquifer varies in thickness from 100 to 600 feet, with an average of 200 feet in the Tract C-a area (Figures 34 and 35). The top of the aquifer ranges from 300 to 700 feet below ground level (Figure 36).

Recharge of the upper aquifer is accomplished through four processes:

1. Infiltration at the outcrop area to the west of the tract;
2. Possible slight infiltration from other aquifers above and below the upper aquifer;
3. Pump tests and piezometric levels indicate there is a natural connection to the lower aquifer in the northeast part of the tract;
4. Recharge also occurs beneath the ridges on the tract due to rainfall and snowmelt (Figure 37) (Rio Blanco Oil Shale Co., February 1981).

The lower aquifer is defined as the water-bearing interval from the bottom of the R-4 zone to the blue marker. This aquifer occurs in the fractured and vuggy oil shale and marlstone in the "leached zone" of the lower part of the Parachute Creek member (Figures 31 and 32). The fracture porosity and permeability is enhanced by the vugs or cavities which developed as a result of dissolution of soluble saline minerals. The lower aquifer varies in thickness from 100 to 800 feet (Figure 38), with its top occurring 550 to 1,500 feet below ground level (Figure 39).

Recharge to the lower aquifer is accomplished through the following:

1. Infiltration through the outcrop zone west of the site;
2. Downward migration from the upper aquifer through fractures in the aquitard (Rio Blanco Oil Shale Co., February 1981).

In the northeast corner of the tract the piezometric levels are reversed with the lower level aquifer being higher than that of the upper aquifer.

Thus, in this area the water migrates upward through the aquitard into the upper aquifer (Rio Blanco Oil Shale Co., February 1981).

Subsurface Data

Currently, there are 38 drill hole locations on or near Tract C-a (Figure 40). Drilling began in July 1974 by Rio Blanco Oil Shale Company for the baseline data program and is continuing today for dewatering wells in the northwest open pit area of the tract. Existing wells were drilled by either the air rotary method, using a mixture of air, water, and a biodegradable soapy substance to help lubricate the bit and lift the cuttings to the surface, or by mud rotary using a revert drilling fluid. Coring was accomplished with a 6-3/4" diamond core bit and a 60-foot core barrel (Wright Water Engineers, Inc., April 15, 1975).

In late 1974, four large diameter (16-inch) holes were drilled to test the lower aquifer (Wells D16 through D19). Since the holes offset existing coreholes, drill cutting samples were not collected, and a full suite of geophysical logs was not run. However, water samples were collected as usual during drilling. The locations of these holes are given in Figure 41.

Appendix I is the core hole history of Well Ca2, now designated TO-2. This also includes drilling data, logs run, and coring intervals. Also included in this summary are the structural and physical properties of the rock as analyzed by Amuedo and Ivey.

Finally, Table 1 is a summary of the current well status on Tract C-a, and Table 2 is a summary of the well logs available for each location.

Among the logs run the rock quality designation (RQD) logs, and the Fischer assays are of major importance in determining rock properties and exact aquifer locations below the tract. Figures 42 and 43 are examples of an RQD log and Fischer assay respectively.

Well Completions

In September 1974, Rio Blanco presented its completion program for their deep water monitoring holes. It included a dual tubing method of completion, shown in Figure 44, which was to be used on an interim basis not to exceed two years. As shown in Figure 44, at the end of the interim monitoring period, packer and tubing were removed from the hole, 1-3/8" tubing was cemented from the bottom of the lower aquifer to the bottom of the upper aquifer and gun perforated for monitoring the lower aquifer. The upper aquifer had a string of

2-3/4" perforated tubing set opposite the aquifer. If the hole was not required for monitoring after the 2-year period, the dual tubing and packer were removed and the hole was plugged and abandoned. (Figures 45 and 46 illustrate two completion methods employed by Rio Blanco in their monitoring wells.)

Prior to October 1974, all 13 prerelease drill and core holes (those drilled by Amoco, Cameron Engineers, and Tosco) were left open. This allowed waters from the two aquifers to intermingle. As of August 1975, all of these holes were recompleted, successfully isolating the two aquifers except in the northeast corner of the tract (Williams Curtis Wells and Co., October 1977). Figures 47 and 48 illustrate the original upper aquifer and dual aquifer completions made in 1974. Figure 49 is a diagram of the large diameter pump test hole completions (Figure 41). Figure 50 shows the general construction of the aquifer test wells drilled in 1975. Figures 51 and 52 illustrate the pump installations for testing the upper and lower aquifers.

Modifications to well completions have been made through time on Tract C-a. Figures 53 through 60 illustrate the well completions during 1977. The most recent well completion diagrams available are those for 1979 as shown in Figures 61 through 71.

Aquifer Tests

During the drilling of the wells on Tract C-a, data were collected using several different techniques. The water production during drilling was monitored continuously with a Parshall flume and stilling well adapted with a Stevens-type F recorder. As the water production increased and decreased the water level fluctuations in the stilling well raised and lowered the float device attached to the recording drum and pen. Upon converting this recording to gallons per minute a plot and evaluation of production versus depth could be made.

Aquifer potential was also examined through "informal pump" tests. These tests consisted of "pumping" the wells by air lift methods for approximately two hours. The hole was then monitored and recovery data collected for two hours. During drilling on Tract C-a these tests were run at two separate intervals: 1. after the B-groove was penetrated the water level recovery was measured with a wire-line pressure recorder; 2. at total depth a similar test was run with the recovery data collected by a downhole pressure recorder inside the drillstring (Rio Blanco Oil Shale Co., March 1976-May 1976).

These aquifer pump tests were used to determine the aquifer transmissivity and storage coefficient, aquitard characteristics such as permeability, and the aquifer recharge and barrier boundaries. The production rates were monitored in gallons per minute with pump placement as shown in Figures 51 and 52. The aquifer transmissivity and storage coefficients were calculated by the simplified Jacob's method using data from both the pumping holes and all effected observation holes. These determinations consisted of semi-log plots of drawdown versus time (Rio Blanco Oil Shale Co., March 1977).

Appendix II is a typical completion report for core hole No. 6 as evaluated by Wright Water Engineers. Similar reports are available for seven other wells in Progress Report 1 (Rio Blanco Oil Shale Co., March 1976-May 1976).

The aquifer pump tests were conducted from January 1975 through June 1975. These tests included the monitoring of drawdown and recovery in both the production holes and all observation wells. The water levels in the production holes were monitored with an air line. All observation holes were monitored with an electric water-level indicator.

These tests included monitoring the pumping rates and total pumping time. Also, water temperature, conductivity and pH were monitored as well as water samples collected for laboratory analysis.

The pump test program consisted of 4 upper aquifer tests and 4 lower aquifer tests. The 4 upper aquifer tests were in wells TO-3, CE-705A, GS-12, G5-4-5, and initially CE-701. The test in well CE-701 was unsuccessful as it was pumped dry within a few minutes. Following this unsuccessful pump test on well CE-701 it was used as an observation hole (Rio Blanco Oil Shale Co., June 1976-August 1976). The lower aquifer pump tests were conducted on wells GS-D16, GS-D17, GS-D18, and GS-D19.

Pump test summaries for the 8 wells on Tract C-a from 1975 through 1977 are shown on Tables 3 through 6.

Tables 7 through 10 summarize the individual aquifer characteristics as determined through the pump tests.

In the upper aquifer, analysis of the pump tests showed an elongation of the cone of depression along a NNW-SSE axis.

The drawdown cones are elliptical, as shown in Figure 72, suggesting an anisotropic aquifer. This is probably a result of the geologic structure in the vicinity of Tract C-a, with fault and joint or fracture orientations influencing water movement. The faults act as barriers and the fractures act as preferential flow paths. A good example of this is shown in the drawdown diagram for well G-S 12, Figure 73. As might be expected, the upper aquifer responded only locally to stresses created during pumping (Rio Blanco Oil Shale Co., December 1977-November 1978). Orientation of the drawdown curves is about N23°W and is controlled by the major faults and joint sets which also possess a NW-SE trending axis (Rio Blanco Oil Shale Co., February 1981).

In the upper aquifer, the regional flow is toward the northeast with a gradient of 100 to 150 ft/mile (Figures 74, 75 and 76). Other water level data are shown in Tables 11 and 12. The transmissivity and storage coefficient for the upper aquifer are shown in Figures 77 and 78 respectively and summarized in Table 13.

Finally, representative hydrographs and other well data plots are shown in Figures 79 through 81.

In the lower aquifer, analysis of the pump tests also showed an elongation of the cone of depression along a NNW-SSE axis as shown in Figure 82. This aquifer drawdown diagram shows a slightly elliptical pattern suggesting it is somewhat less anisotropic than the upper aquifer. Each of the pump tests of the lower aquifer generally affected all of the lower aquifer observation holes. Thus, faults present in the lower aquifer may not act as hydraulic barriers as significantly as they do in the upper aquifer. Therefore, calculations of transmissivity and storage coefficients are more reliable than the upper aquifer values (Rio Blanco Oil Shale Co., July 15, 1975).

The piezometric gradient in the lower aquifer generally trends toward the east at 5 to 30 ft/mile (Figures 83 and 84). Other water level data are given in Tables 14 and 15.

Figure 85 shows the transmissivity of the lower aquifer in gallons per day per foot. The flatter gradient, without a significantly different transmissivity, indicates that locally the groundwater movement in the lower aquifer is much slower than in the upper aquifer (Rio Blanco Oil Shale Co., February 1981). Figure 86 is a diagram of the storage coefficient data and Tables 16 and 17 are a summary of the lower aquifer drawdown and recovery test data. Figures 87 through 89 illustrate plots of drawdown and recovery data for the aquifer.

In October 1977, Rio Blanco proposed a dewatering and reinjection program for its revised MIS project. This program was reviewed by Wright Water Engineers, William Curtis Wells & Co., and Rio Blanco Oil Shale Co. (Rio Blanco Oil Shale Co., September 1977; William Curtis Wells & Co., October 1977; Wright

Water Engineers, Inc., November 1972). Twelve dewatering wells were proposed to be drilled in a circular pattern around the mineshafts, drifts and oil shale retorts. These wells would tap only the upper aquifer with a thickness of 200 to 250 feet at a depth of 450 to 750 feet below ground level. This dewatering program expected to lower to groundwater table to about 1,000 feet. Figure 90 illustrates the typical dewatering well construction.

Also included in this program were a proposed twelve reinjection holes. These were to be situated to minimize this cone of influence caused by the mine water pumping.

The present dewatering/reinjection system operates in such a manner as to preclude significant piezometric drop within a distance of 2/3 mile from the 14 acre area to be mined. The bulk of the water pumped from the dewatering wells is directly piped to the reinjection wells. The water is reinjected into the aquifer from which it comes. Reinjection well dimensions and details are illustrated in Table 18 and Figures 91 and 92, respectively.

The conceptual layout for the dewatering/reinjection program is shown in Figure 93. Table 19 summarizes the future use of drill holes as of September 1977. This should be compared with the current well status summary given in Table 3.

The dewatering/reinjection program is continuing at the present time. Dewatering by wells GS-D1 through GS-D5 have completely dewatered the present retort areas. Reinjection around the tract periphery continues to contain the advancing cone of depression. Table 20 is a daily dewatering/reinjection report for the middle of March 1981.

As shown in Figure 94, the MIS retort is in the center of the cone of depression. The spread of this cone of depression is in a NE-SW direction but is inhibited by both the directional permeability characteristics of the upper aquifer and faulting which inhibits movement of groundwater. Thus both dewatering and reinjection in the upper aquifer system may result in a response similar to that of an aquifer divided into cells only partially connected hydrologically.

On the other hand, the lower aquifer displays no response to dewatering and a limited response to reinjection in the northeast corner of the tract where the two aquifers are not totally isolated (Rio Blanco Oil Shale Co., March 1980).

Along with the monitoring of water production and aquifer potential, geophysical logs were run on most wells as previously listed in Table 2. Of these logs, the spinner and temperature surveys are most valuable in hydrologic interpretation. These two logs are used to determine the direction and velocity of flow within the wellbore. Figures 95 and 96 are examples of plots made from this data.

Groundwater Quality

On Tract C-a, deep aquifer monitoring was initiated in December 1974, and included only measurements of static water levels. In March 1975, water sampling of the monitor holes was begun (Rio Blanco Oil Shale Co., May 1977). Monitoring data included water levels, water temperature, and chemical analyses.

During drilling in 1974, water quality was tested at 30 foot intervals by measuring conductivity, pH, and temperature. Also, water samples were collected at each of 4 intervals during drilling:

a) First significant production;
b) End of the B-groove pump test;
c) Increase in production after B-groove;
d) At total depth.

These samples were analyzed through both standard wet chemical and spectrographic methods (Rio Blanco Oil Shale Co., 1974).

Currently, water quality monitoring is conducted in the following manner:

1. Weekly: Water level measurements
    A) Upper aquifer: Monitored daily in 14 wells and weekly in 6 others;
    B) Lower aquifer: Measured daily in 1 well and weekly in 5 others.
2. Monthly: Water level measurements and field measurements of water quality (pH, temperature, and conductivity).
    A) Upper aquifer: Samples collected at 10 wells.
    B) Lower aquifer: Samples collected in 1 well.
3. Quarterly: Basic water quality analyses performed.
    A) Upper aquifer: Sampling is done in 3 wells.
    B) Lower aquifer: Sampling is done in 5 wells.
4. Annually: Basic water quality analyses and trace constituent analyses.
    A) Upper aquifer: Samples collected in July at 6 wells.
    B) Lower aquifer: Samples collected in July at 5 wells (Rio Blanco Oil Shale Co., October 1977 and March 1980).

Sample collection on Tract C-a is accomplished through the use of a special stainless steel bailer.

Tables 21 and 22 are examples of Rio Blanco's approach to hydrologic monitoring. Tables 23 through 27 illustrate the changes through time of the monitoring program. Tables 26 and 27 are the most recent programs outlined in their modified detailed development plan, Lurgi project.

During the baseline monitoring program water quality data were collected for use as a standard during project development. Tables 28 and 29 show drinking water quality standards and Tract C-a groundwater compared to these standards, which may also be compared to the values presented in the baseline water quality summaries shown in Tables 30 and 31 (Rio Blanco Oil Shale Co., May 1977). Table 32 shows a comparison of this baseline data to information collected to 1980 (Rio Blanco Oil Shale Co., March 1980).

Tables 33 through 36 illustrate data obtained through wet chemical analyses and qualitative spectrographic analyses performed on these water samples.

Finally, a water quality analysis was run on the reinjection water, with results shown in Table 37 (Rio Blanco Oil Shale Co., September 1977). These data were compared to individual well data and are summarized in Table 38 (Rio Blanco Oil Shale Co., September 1977).

Water quality monitoring has shown the upper aquifer water to be very hard and mildly alkaline, with a total dissolved solids concentration of approximately 900 mg/l. The predominant anions are bicarbonate and sulfate; sodium is the dominant cation. These 3 constituents account for 90% of the total dissolved solids. Also in the upper aquifer, calcium, magnesium, and sulfate are generally inversely related to the rest of the major constituents, and precipitation of calcium carbonate may be taking place (Rio Blanco Oil Shale Co., February 1981; William Curtis Wells & Co., October 1977).

The lower aquifer water is moderately hard and alkaline with a total dissolved solids concentration of approximately 1,100 mg/l. Bicarbonate and sodium are the predominant ions in solution and account for 75% of the total dissolved solids. It is common at Tract C-a for total dissolved solids to increase with depth as the water accumulates dissolved solids from the rock as it percolates downward. For the ionic species though, this is not necessarily true. Ion exchange or solution-precipitation processes result in the replacement of one ion by another. Thus, the concentration of calcium, magnesium, sulfate, and silica decrease with depth and are replaced with sodium and bicarbonate ions (Wright Water Engineers, Inc., November 1972).

On Tract C-a there is usually a decrease in calcium and magnesium from the upper to lower aquifers. This is contrasted with a significant increase in sodium concentration from the upper to lower aquifers. This can be explained by the presence of nahcolite and dawsonite which contain exchangeable sodium. The groundwater migrates downward and the calcium and magnesium in solution are exchanged for sodium. Also, the pH in the lower aquifer is slightly basic (7.5) which encourages the precipitation of calcium carbonate. This also explains the lower hardness in the lower aquifer (Wright Water Engineers, Inc., November 1972).

Finally, as would be expected, the water quality in the northeast corner of the tract is poorer than elsewhere. This is most likely due to the unsuccessful isolation of the two aquifers in this area (Rio Blanco Oil Shale Co., March 1975-May 1975).

Figures 97 and 98 and Tables 39 through 42 show typical data obtained in the water quality monitoring program, and Appendix III lists the complete set of data for 1980.

GEOLOGY OF TRACT C-b

The Uinta Formation is the only bedrock unit exposed at Tract C-b (Figure 99), but quaternary colluvium and alluvial deposits occur in the valleys and on hillslopes. A generalized cross section at the tract (Figure 100) illustrates the stratigraphic subdivisions, which are essentially the same as those at Tract C-a. Figure 135 shows detailed lithologic logs, fracture density logs, and density logs correlated with stratigraphic nomenclature and aquifer units in the vicinity of the MIS retort area. Figure 101 is a structure contour map of the top of the Mahogany zone. Figure 102 is a stereographic net contour diagram showing joint measurement data from 39 locations on the tract. Joint directions are prominently bimodal, as at Tract C-a.

The retort zone, including overlying air levels and underlying gas levels, includes a thickness of the Parachute Creek member from just above the A-Groove to near the bottom of the L-5 zone (Figure 135). Fracture densities vary within this section from more than 10 to zero per 10 feet of core described. Numerous tuff beds, vuggy zones, solution breccia zones, saline mineral nodules, and various types of fracture fillings are common in this zone (Figure 135).

Probably the most important aspects of tract geology related to groundwater are that no faults have been discovered on the tract, and that individual rich oil shale beds are traceable laterally throughout the tract. This has allowed the distinction of separate aquifer and aquitard units across the tract. For example, the thin A-groove and B-groove units can be expected to produce larger quantities of water than the Mahogany zone dividing them (Figure 135). In addition, the preferred orientation of joint patterns can be expected to produce a definite anisotropy of permeability on the tract.

As part of the lease requirements, measurements of trace elements were made in cores taken at Tract C-b. The results of this study, which included antimony, arsenic, boron, cadmium, fluoride, mercury, and selenium, are graphically displayed in Appendix IV, which shows excessive concentrations of fluoride and boron in the "lower aquifer."

Tract History

On April 1, 1974, The Department of Interior awarded Atlantic Richfield, Ashland Oil, Shell Oil, and Tosco the original lease to Tract C-b for a bonus of $117,778,000.36. The lease terms required that a 2-year baseline environmental program be developed. The baseline period ended October 31, 1976. During 1975, Atlantic Richfield and Tosco withdrew from the partnership. Shell withdrew in November 1976, when the remaining partner, Ashland, obtained agreement from Occidental to use their MIS process. After a one-year suspension of the lease from 1976 to 1977, the MIS modified detailed development plan was submitted. In January 1979, shaft sinking was begun, and in September 1979, Tenneco Shale Oil Company bought a 50% interest in the project. Today shaft sinking is continuing. Initial retorts are planned for firing by 1985. Full-scale production of 57,000 barrels of shale oil per day is planned by 1985.

Subsurface Data

Approximately forty coreholes or water wells have been drilled on Tract C-b. All wells drilled on the tract and within a two-mile perimeter are shown in Figure 103, and listed in Table 43 (injection well #1 has been added to the map and is not listed in the table). Table 43 lists the original designations of the wells and their corresponding computer codes for water quality analysis records. Figure 104 is a larger scale map showing the wells on the tract in relation to topography and surficial features. In addition, Figure 135 shows the subsurface data from holes 33X-1 and 32X-12, which were drilled and tested in 1977 to provide subsurface information in the area where the three shafts are now being sunk. The types of data collected for all wells drilled for and during the baseline monitoring program are summarized in Table 44, and the locations of data in the various quarterly data reports are also given. Data pertaining to hydrologic tests and aquifer characteristics are reproduced in the pertinent sections of this report.

The sampling intervals and periods of water quality data are listed in Table 45.

Well Completions

Based on the original USGS interpretation of lower and upper aquifers separated by the Mahogany zone aquitard, the wells constructed for the 2-year baseline monitoring program were designed and completed to test both aquifer and water characteristics of the two aquifers and the aquitards. Figures 105 and 106 illustrate the relationships between well depth, perforated zone, and stratigraphy for wells sampled during the baseline monitoring program. The detailed as-completed design of well SG-11 (Figure 107) illustrates engineering details. Note that the well was cemented through the aquifers and then perforated by shooting 1-9/16" holes at one-foot intervals in the selected zones. This cement-perforation method makes additional aquifer testing impossible, although water quality samples can be obtained.

As a result of aquifer test results obtained during the baseline period, twenty of the wells at Tract C-b were reworked in 1980. Figure 108 shows the present completion scheme in relation to aquifer stratigraphy. Details of well construction for each recompleted well are shown in Appendix V. Wells are now completed with as many as four casing strings in order to monitor one or more of the four zones. Currently 14 strings monitor the UPC_1 aquifer, 15 strings monitor the UPC_2 aquifer, 17 strings monitor the LPC_3 aquifer, and 3 strings monitor the LPC_4 aquifer. The thicknesses of perforated zones in the different aquifers are shown in Appendix V. Seventeen wells were designed as part of the reinjection system to control dewatering of the aquifers. Of these, only well #1, near well SG-10, has been completed and is being used for injection. Figure 109 shows the locations of the injection wells and nearby monitor wells; Figure 110 shows the design of the injection wells. Note that the injection wells will be 6-1/4" open hole in the retort zone.

Aquifer Tests

Initial aquifer tests during the baseline monitoring program at Tract C-b were based on the earlier concept of lower and upper aquifers separated by the Mahogany zone aquitard, as identified by the previous regional USGS work.

Table 44 lists the type of hydrologic tests done for each well constructed during the monitoring program or before, and it contains the location of the original data for each test. These data were inspected in the area oil shale office in Grand Junction, and are summarized in Figures 111 through 116. Note that wells Cb-1, Cb-2, Cb-3, and Cb-4 were drilled prior to the baseline program and, unlike the other wells, do not have hydrologic test data. Also, note that the NQ wells are actually slant core holes in which hydrologic testing was not done.

The most basic type of aquifer test that was done was maintenance of water production data during drilling (Figure 111). Such data are collected by measuring flows through a measuring flume between the well head and the waste pit. Drilling water production during air mist drilling, as was done for the core holes at Tract C-b, fluctuates due to temporary storage in the well bore, water lost to or added from strata up the well bore, and operational procedures necessary during drilling (for example pulling core barrels, etc.). For Tract C-b wells, production was measured at approximately thirty feet intervals (Figure 112). Water production data collected in this manner are thus cumulative with depth and are indicative only of large scale changes in aquifer properties. They cannot be used to identify precise quantitative properties of aquifers within individual producing zones.

Realizing the limitations of practical application of water production data, the Tract C-b leaseholders also conducted jetting tests of the wells (Table 46), by temporarily halting drilling at a predetermined depth and blowing air down the hole through the drill pipe for approximately a two-hour period. This procedure discharged water from all producing zones above the depth of jetting. From the basic production data, transmissivities were calculated for open hole distances (Table 46).

Like water production data obtained during drilling, jetting production data are not representative of properties of individual aquifers within the entire section being tested, and only provide a general indication of relative increases or decreases of water production with depth in the well. Recent attempts by researchers at Tract C-b to predict dewatering rates and piezometric surfaces due to the proposed MIS plan led them to conclude that the transmissivities derived from jetting tests were not reliable data, considering that the discharge data were obtained by jetting (C-b Shale Oil Project, Reinjection Application Permit, 1978 and 1979).

The most detailed and useful aquifer tests conducted at Tract C-b have been drillstem tests and pumping tests. Drillstem tests (DST's) involve using packers to isolate a selected vertical section of strata and measuring fluid pressure changes in the packed off zone under natural or artificially imposed head conditions. At Tract C-b, nearly 40 DST's were run on well SG-17, in the southeast corner of the tract. Two DST's were run in each of wells SG-20 and SG-21.

The results of these tests are shown in Table 47, and examples of the determinations of coefficients are shown in Figure 113. The initial calculations of coefficients, published in the final hydrology baseline report, were found to be erroneous, and corrections were made by Energy Consulting Associates (ECA) in the reinjection report. The transmissivities calculated by ECA for well SG-17 are graphically shown in Figure 135, correlated laterally with stratigraphy, water quality from individual test zones, retort zone location, and the bulk density log. It should be noted from Figure 135 that the highest transmissivities in the MIS retort zone are associated with the A and B grooves (above and below the Mahogany zone), which are lean oil shale zones traceable throughout the Piceance Basin.

Pumping tests have been conducted at four different locations on Tract C-b. In the extreme northwest corner of the tract, at wells SG-1 and SG-1A (Figure 104), four zones were tested by what were called "mini pump tests." Each zone was isolated in both wells by means of packers, and water was pumped from one well while observations of water level were made in the other well. The tests were designed to obtain information on vertical permeability of small layers using comparisons of pressure responses to pumping in different layers. Jetting was used rather than actual pumping. Figure 113 illustrates the conditions and results of one such test, and Tables 48 and 49 show the intervals isolated and results. Because of the design of the test (assumptions were made concerning rock properties, Table 48 and expected values of vertical permeabilities), the results can be considered to be only qualitative. In addition, because of packer problems, only the results from tests 4, 6, 8, and 10 were considered reliable and were reported by Tract C-b (Table 50). Therefore, because of the large thicknesses of strata tested and the qualitative nature of the tests, only the qualitative conclusion that the vertical permeability of the richer oil shale beds was made (C-b Shale Oil Project, Reinjection Application Permit, 1978 and 1979).

A series of pumping tests was conducted involving six closely spaced wells (AT-1 through AT-1C) near the center of the tract and four additional observation wells (Table 51). Well AT-1 was pumped with a submersible pump, first including only the strata above the Mahogany zone (total depth 1,338 feet). Then the well was deepened (total depth 1,700 feet) and another pumping test was conducted (Figure 114). The tests were designed to stress the previously defined "upper" and "lower" aquifers. Porous media conditions of flow were assumed and Darcian-based methods of analysis (type curves) were used. The initial computations of aquifer transmissivity, storage, and leakance presented in the hydrology final baseline report were found to be erroneous when reexamined. Values for storativity could not be obtained for all wells because of lack of knowledge of flow conditions, but calculations of T and S that were possible are shown in Tables 52 and 53. Examples of the type of curve solutions used are shown in Figure 115.

The most recent test results available from Tract C-b are those from construction of wells 33X-1 and 32X-12, developed during pumpspinner productivity tests during May 1977 (Figure 135). Based on these relative values of productivity, permeabilities were assigned (Table 54) and transmissivities were estimated for 18 aquifers in well 32X-12 and 17 aquifers in wells 33X-1 (Tables 55 and 56).

In summary, aquifer tests at Tract C-b began as attempts to define the hydraulic and water quality characteristics of the lower and upper aquifers as originally defined by the USGS. However, as more became known from the detailed drill stem and pump-spinner tests, it became obvious that several numerous, thin, laterally extensive aquifer units exist and are separated by beds of extremely low vertical and horizontal permeability (Figures 116, 117, and 118). Units considered to be aquifers appear to vary over two orders of magnitude in permeability (Table 54), and may be as thin as ten feet. Hence, initial data obtained during the baseline monitoring program and up to the present integrate properties of several aquifers and mask individual aquifer differences. The aquifer properties of the retort zone used to design the reinjection system and model the results are shown in Table 57. The thicknesses of zones perforated in the retort zone aquifers are shown on Table 58.

Water Quality

Water samples have been collected for quality analysis since initial drilling began for the baseline monitoring programs, and data exist also for a few wells drilled before the lease acquisition. Water temperature and electrical conductivity were measured along with discharge at approximately 30-foot intervals during drilling. Examples of results are shown in Figures 119 through 122, showing minimum quality data. In addition, jetting tests to collect water samples were done at the base of the Uinta Formation, the top of the Mahogany zone, the base of the Mahogany zone, the top of the R-4 zone, and at total depth. Depth-conductivity curves across the tract are shown in Figure 119, and complete water analyses from a jetted well are shown in Table 59. As noted in the drilling report summary, quality data obtained during drilling integrate quality properties of all water entering the hole from bit depth to surface. Therefore, these data are of a very general, qualitative nature and do not reflect the detailed quality of water from individual aquifers within the section.

In order to obtain the most detailed quality data possible, water samples were collected during the pumping and drill stem tests previously discussed.

Tables 60 and 61 list the depths and thicknesses tested for drill stem tests of wells SG-1, SG-20, SG-21, SG-8, and SG-17. Figure 122 shows the variation of total dissolved solids with drill stem interval in SG-17. Other analyses for different horizons are shown in Figure 135 for this well.

Water quality samples were collected twice a year from each well during the 2-year baseline monitoring program. These data are shown in their entirety in Appendix VI. Samples were obtained by swabbing. Table 62 shows the swabbing record for the fall 1976 sampling run. A string of 2-3/8" diameter contains approximately one-fourth gallon of water per linear foot. Based on the records of water swabbed, it appears that adequate samples were obtained of water from within the aquifer and not water sitting in the well. Water quality analyses were run by Industrial Labs, Denver.

An additional opportunity to sample water from different units occurred in 1977 during the drilling of test wells near the proposed shaft sites. Figure 123 shows the Stiff diagram for well 33X-1, the only data from this drilling contained in these well files in the AOSO. The water samples represented by Figure 123 are composite, as they were obtained during pump-spinner tests of the well.

The water monitoring schedule currently in use (Table 63) shows that pH and water level are measured monthly, while other parameters are measured every six months. Table 64 shows the data collected for all wells for a recently reported sampling run.

All water quality analyses are kept on computer.

Water Levels

As indicated by Table 63, water levels are measured on a monthly basis. Graphs of water levels versus time for all wells for the baseline monitoring program were published in the Baseline Hydrology Final Report (1976); Figure 124 shows the graph for Well SG-22, string #2. Table 65 lists the most recent published data for the tract for all wells.

Maps of water levels contoured for individual aquifers show the configuration of the piezometric surface and direction of water movement (hydraulic gradient). The hydraulic gradients of all aquifers distinguished thus far have generally been from south to north; Figures 125 through 127 show the gradients for the "upper" and "lower" aquifers and for the LPC3 zone. However, the recent dewatering-reinjection operation has altered the flow conditions in the upper 3 aquifers (Figure 135), creating a "cone" of depression in the vicinity of the shafts near the northwest central portion of the tract (Figure 128). A current map showing the configuration and extent of the cone will be prepared from current data, scheduled for submittal this month. However, Table 65 shows that even by the end of 1979, significant decreases in water levels due to shaft dewatering were being experienced by wells more than a mile from the shaft area. The recent well recompletions and reinjection activities, completed within the last year, undoubtedly will alter these data significantly, however.

Water level data are important to our proposed test-site selection. Because velocities of groundwater are controlled partially by hydraulic head differences, the best experimental area would be one with natural (not artificial) head differences between two points in the same aquifer. Of course, this condition will not be attained near the dewatered zone. A test in reinjection zones of higher head differences will also be in an abnormal area, but could involve acceptable conditions if the difference were not excessive.

MIS Retorting

Unlike at Tract C-a, where surface, open-pit mining is a feasible alternative to MIS retorting, at Tract C-b the alternatives are either underground mining or the MIS method. The extensive experimentation at Logan Wash done by Occidental, plus their substantial financial commitment and development activities at Tract C-b, indicate that MIS retorting will be the method used there. Figures 129 and 135 show the retort zone in relation to oil shale assay values, stratigraphy, aquifer units, and other data. Figure 130 shows the locations of surface plant facilities, shafts, and initial retorts. Figure 131 shows the area ultimately projected for MIS retorting. Dewatering-reinjection well locations are shown in Figure 109.

The MIS process involves dewatering the retort zone and retorting the shale in a progression of clusters of retorts successively developed underground. Groundwater will thus be withheld from reentering the MIS area until the entire site has been processed. Figure 131 shows that each retort is 200 feet square with a 30-foot boundary of unretorted shale, which will also become physically and chemically altered during a burn. Therefore, a total area of approximately 2/3 of a square mile of altered oil shale retort zone will become rewatered after dewatering ceases.

Regional Models

For the models thus far used to predict the effect of mining, standard Darcian models of groundwater flow have been used. These are based on the assumptions that the aquifer being modeled is isotropic and homogeneous, and that the flow is laminar. Of course these conditions are not met in oil shale aquifers. Nevertheless, Darcian models have been used because they are readily available with only minor modification necessary, and because additional assumptions are possible. These assumptions are that the fractures are dense, the tests are long, the cone of depression is large, and artesian conditions exist (Rio Blanco Oil Shale Project, 1976). However, the utility of such models for the oil shale aquifers remains in question and can be decided only after actual field experimentation and data collection. Figures 132 and 133 illustrate the results of models at Tracts C-b and C-a, respectively.

Models Based on Fracture Flow

One solution to problems with existing models based on intergranular permeability has been to employ models based on fracture flow (Freeze and Cherry, 1979). Although fracture flow technology is still very much in the research stage, a field example of its preferential results was recently provided by Neuzil (1980). In field and laboratory tests of hydraulic conductivity of the Pierre Shale, he observed a large discrepancy of values between regional flow data and local flow data (Figure 134). He was able to explain this discrepancy quantitatively by analyzing the fracture flow, known to be significant, with a modified Poiseuille equation. Like previous fracture flow results, it included shape, size, and roughness of fractures, but it also incorporated information on the relative abundance of apertures of different size. He then used his equation to predict contamination from a point source. These types of research results will likely be of help in developing the accurate predictive model necessary to predict the local effect on groundwater near an MIS retort, wherein regional flow models yield results too general for the required purposes. Despite such advances, the conclusion was reached by Freeze and Cherry (1979, p.409) that an earlier statement in 1972 by Castillo et al. regarding this problem is still applicable:

"Although the basic theoretical aspects of...(dispersion)...have been treated at length for the case where the permeable stratum is composed of granular materials, the classical concept of flow through a porous medium is generally inadequate to describe the flow behavior in jointed rock, and it becomes increasingly unsuitable for the analysis of dispersion. Despite these limitations, little work has been directed toward extending these ideas to handle flow through jointed rock formations (p.778)."

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SECTION 2

MINERALOGY OF THE GREEN RIVER FORMATION

INTRODUCTION

The Eocene Green River Formation, host to the rich oil shales of the Piceance Creek Basin, has long been of interest to mineralogists due to the occurrences of rare and unusual minerals within its strata. The earliest investigations into the genesis and mineralogy of this formation were carried out by Bradley (1929a, 1929b, 1931, 1936, 1948). Since that time, hundreds of studies have been carried out by researchers on core cuttings and cores from the Piceance, Uinta, Green River (Bridger) and Washakie Basins in Colorado, Wyoming and Utah (Figure 136). These studies, discussed in this section, build up a picture of an amazingly diverse formation composed of authigenic carbonates, silicates, sulfides, sulfates, halides, oxides, hydroxides, phosphates and hydrocarbons in a highly stratified sequence of sediments covering over 16,000 square miles of a three-state area and representing the single largest oil resource presently known in the United States.

GENERAL

Milton and Eugster (1959) state that "It is not a simple matter to estimate the mineral composition of the Green River rocks as a whole, or even regionally." Nonetheless, they are willing to venture the bulk of the formation as being composed of detrital clays, quartz, feldspars and ferromagnesian silicates (hornblende and biotite) and a primary abundance of authigenic dolomite, calcite, quartz, trona, shortite, pyrite and clays. Widespread, though not necessarily abundant, are analcime, shortite, searlsite, and barytocalcite. Less abundant, but locally concentrated, they report trona and nahcolite. A host of other minerals confined to a single known occurrence or found only rarely and sparsely are reported. Milton later updated the list of known minerals and their relative abundances in a 1977 paper. In this list more than eighty minerals are named as occurring in the Green River Formation. In the intervening eighteen years, thirty new minerals were added to the 1959 list, seven of which had only to that date been found in the Green River Formation, fourteen as single, fortuitously encountered occurrences.

In the 1977 review paper, Milton, who has devoted a large portion of his entire career to the study of the Green River Formation, makes two important points. First, that "...formation temperatures could hardly have exceeded 250°C..." and second, that from a study of many cores from the Piceance Basin (Smith and Milton, 1976, unpublished data) it appears that "...in Colorado, the Green River beds, which are several thousand feet thick, may be horizontally zoned by specific assemblages of authigenic minerals, with virtual constancy in overall chemical composition from top to bottom."

The first point is supported by equilibrium studies in the systems $NaHCO_3 - Na_2CO_3 - CaCO_3 - H_2O$, and $Na_2CO_3 - CaCO_3 - MgCO_3 - H_2O$ shown in Figures 137-138. P_{CO_2} - T diagrams were recalculated by Milton and Eugster (1959) from the data of Freeth (1923) for the system $NaHCO_3 - Na_2CO_3 - H_2O$ while P_{CO_2} - T curves for part of the system $NaHCO_3 - Na_2CO_3 - CaCO_3 - H_2O$, the saline beds, and curves involving the silicate phases were constructed on a relative basis, the P_{CO_2} and T values of invariant points being unknown at the time.

The two points mentioned by Milton above will have far-reaching effects when we consider MIS processing later in this paper.

In general, the mineralogy of the Green River beds can be regarded as the outcome of interactions between highly sodic solutions and carbonate muds. The differences in authigenic mineralogy within the formation between the various depositional basins can be attributed to variations in the partial pressure of CO_2 and the temperature between these basins at the time of formation. In view of these variations, each of the basin complexes will be discussed separately.

MINERALOGY OF THE GREEN RIVER-WASHAKIE BASIN COMPLEX

For the purposes of this report, the Green River (Bridger), Great Divide and Washakie basins will be treated as a single depositional entity during the majority of the lifetime of Lake Gosiute which, at one time, covered both basins as we know them today.

The Green River Formation in the Green River-Washakie complex is subdivided into three members, the uppermost Laney Shale, middle Wilkins Peak and lowermost Tipton Shale (see Figure 139 for generalized stratigraphic section). The Wilkins Peak is sometimes subdivided again into an upper, lower and middle member.

The Laney Shale consists of interbedded sandstones, siltstones, organic shales and oil shales.

The Wilkins Peak member is host to the saline trona and halite deposits of the Green River Formation in this basin complex. Dolomitic shales, mudstones and shortite-bearing shales are also present in this member. There is a gradual grain size increase toward silt and sand in this member toward the basin edges.

The Tipton Member consists of dolomitic shales, organic shales, oil shales, limestone and several altered tuff beds.

Bradley (1964) reconstructs the depositional history of Lake Gosiute as follows. Three stages of deposition covering a period of 4 million years took place, each stage correlating with one of the three recognized members. The Tipton Shale (lowermost) was deposited over a period of approximately 1 million years during a time when the lake waters were fresh. There then followed a period of aridity during which time the lake shrunk and lost its outlet. At this time, approximately 1 million years in duration, the evaporites and other beds of the Wilkins Peak member were laid down. Finally, in the last stage of deposition (2 million years) the Laney shale member was deposited under humid conditions when the areal extent of Lake Gosiute was at its largest. Eugster and Surdam (1973) later refuted this model and proposed a playa-lake model instead. This model consists essentially of a large alkaline playa fringing an alkaline lake wherein water and salinity levels fluctuated frequently and communication between the lake and playa was sporadic. The principal point of contention is the rhythmic bedding of organic-dominated beds with evaporite-dominated beds; the two being presumably depositionally exclusive. One must either postulate a permanently stratified lake or construct a model which is inherently flexible enough to take this depositional sequence into account without invoking rapid climatological fluctuations.

It is within whichever depositional framework one chooses to believe that we can place the mineralogical occurrences and associations seen today in the Green River beds.

A list of the minerals known to occur in these beds within the present day Green River-Washakie complex is given in Table 66.

Sulfur has been seen as microscopic yellow crystals associated with secondary sulfates in weathered shale possibly derived from the reduction of sulfides by organic matter (Milton, 1971 and 1977). Its occurrence was also noted in Bradley (1964) where he notes that J.D. Love detected a marked sulfur smell when breaking a core of one of the salt beds from the lower Wilkins Peak Member. Sulfur was also verified as an inclusion by microprobe in this paper.

Pyrite occurs ubiquitously throughout the formation in massive habit, euhedrally in trilling twins and in a skeletal habit (Milton and Eugster, 1959; Pabst, 1970). Other sulfides, pyrrhotite, marcasite and wurtzite are reported as rarely occurring (Milton and Eugster, 1959).

Only two halides have been found to date in these beds, neighborite and halite. Neighborite was first discovered in the Green River beds in Utah but was later also found in Wyoming (Chao et al., 1961; Milton, 1977). It occurs only rarely. Halite has been reported exclusively in the Wilkins Peak member generally associated with trona, but occasionally in pure, thin beds (Deardorff, 1963).

Quartz is, of course, ubiquitous in the Green River beds. Milton (1971) reports it as occurring in "microscopic stubby prisms...free from visible inclusions." Chalcedony is also reported as ubiquitous in massive bedded form. Mention of anatase as inclusions in detrital K-spar and quartz is made in Bradley and Eugster (1969). This is the only mention of anatase other than a note in Milton (1977) which refers to an occurrence in the altered tuffs.

Calcite and dolomite are widespread and abundant in the Green River Formation of Wyoming. They can occur both in massive form or finely disseminated as in oil shale. The occurrence of nahcolite in Wyoming is very restricted. Milton and Eugster (1959) show that nahcolite and trona are inversely related and that at an atmospheric concentration of CO_2, nahcolite will be the stable phase below 35°C whereas trona, which is abundant in these beds, must form above 35°C at CO_2 levels in equilibrium with the atmosphere (Figure 140).

In no case could it form below 20°C. Although thermonatrite is mentioned as occurring extremely rarely in at least three papers, Milton and Fahey (1960), Milton and Eugster (1959), and Milton (1971), no primary reference as to the mode of occurrence of this mineral can be found. Curiously, Milton (1977) omits this mineral in the list of carbonates. The occurrence of natron is also mentioned in these papers but again, no primary reference could be found as to the mode of occurrence. It is listed in Milton (1977) as nowhere abundant but present in more than one locality. Strontianite is reported as occurring in more than trace amounts, locally but never abundantly in Milton (1971). Smith and Trudell (1968) report encountering aragonite, primarily in shells and shell fragments. Its occurrence in thin beds is also reported in Milton (1971). Milton and Eugster (1959) indicate the presence of witherite and siderite but refer to unpublished data. Witherite again appears in Milton (1971) and (1977) but without reference to habit or association. Its abundance is on a par with aragonite and strontianite; local but never abundant. Reference is also made to its occurrence in association with norsethite in Mrose et al. (1961).

Shortite is found ubiquitously in these beds and was first reported in smectitic shales in association with pyrite and other carbonates (probably calcite and dolomite) (Fahey, 1939). Its occurrence is generally confined to the Wilkins Peak member where its replacement by calcite (Smith and Trudell, 1968) and by bradleyite (Fahey and Tunell, 1941) has been observed.

Pirssonite, gaylussite, bromlite and northupite are reported in Fahey and Tunell (1941) from the same core which first yielded shortite, bradleyite and several other first occurrences in the Wilkins Peak. Milton (1977) lists both pirssonite and gaylussite, compound carbonates, as widespread but only locally abundant. The reference to bromlite, that is alstonite, is virtually the only reference found in the literature to this mineral and one is led to postulate that this occurrence may have actually been the dimorph of alstonite, barytocalcite, which has since been found at several other localities. Northupite is found in the saline zone generally in massive form as an infill material in cracks and vugs.

Norsethite has been found to occur locally and relatively sparsely in the oil shales of the Wilkins Peak member. It was first reported by Mrose et al. (1961) and was found as "clear to milky-white plates" associated with shortite, labuntsonite, searlsite, pyrite and quartz at the Westvaco trona mine in the Green River basin. It was also found in a grey shale at the same locality with the additional association of northupite. The additional occurrence of barytocalcite and witherite in "the waste sodium-carbonate 'mud'" (drilling mud?) are noted in this paper.

Mackelveyite and its historically linked associate, ewaldite, were first found in waste residues at the same trona mine which yielded norsethite. Several other localities in Sweetwater County, Wyoming have also been reported (Milton et al., 1965). It was not until 1971 that these so-called mackelveyite specimens were revealed to be syntactic intergrowths of two minerals, one of which would retain the name mckelveyite (at this time changed to mackelveyite) and a second given the name ewaldite (Donnay and Donnay, 1971). Whereas ewaldite is always found as a syntactic intergrowth with mackelveyite, mackelveyite itself has been found as a pure phase. The association found at the Westvaco mine is with acmite, biotite, quartz and burbankite. This paper also reports the first confirmed occurrence of an authigenic biotite which was analyzed to be a 35-45% iron end-member annite. Both papers mention iron-oxide inclusions in the mackelveyite-ewaldite intergrowths which were shown to be hematite pseudomorphs after magnetite.

The occurrence of tychite and burkeite with northupite is briefly mentioned in Milton (1971), however, both minerals appear to have been found only once and do not appear on the 1977 list.

Finally, at the end of the list of carbonates is wegscheiderite. This mineral had actually been reported from several localities as $Na_2CO_3 \cdot 3NaHCO_3$, an unnamed phase, as early as 1960. In 1963 (Fahey and Yorks) it was finally promoted to the status of a mineral and given the name wegscheiderite. It has, to date, been found only in the Wilkins Peak member in association with trona, nahcolite and halite where it is seen to replace trona and be replaced by halite.

Clay minerals reported in the Green River Formation in Wyoming include kaolinite, illite and montmorillonite (smectite and nontronite). A study by Regis and Sand (1957) revealed illite as being generally associated with loughlinite (a Mg-silicate first found in the Green River Formation) whereas montmorillonite is generally associated with carbonates. Montmorillonite is also reported as a constituent of altered tuff beds in the Tipton Shale Member (Surdam and Parker, 1972). The occurrence of sepiolite (meerschaum) and analcime was documented very early in the history of these investigations by Bradley (1929a). Whereas talc, chlorite and lazurite were not documented until many years later (Bradley, 1965) occurring in the lower Wilkins Peak associated with salt beds.

Stevensite has been reported from more than one locality but was first reported occurring in association with calcite and dolomite in the upper Wilkins Peak by Bradley and Fahey (1962) who report it as occurring in "considerable abundance." Louglinite was first noted from the same well which produced bradleyite and shortite. It was reported by Fahey, Ross and Axelrod (1960) as occurring in dolomitic oil shale, replacing shortite, northupite and searlsite. Regis and Sand (1957) note that loughlinite is always associated with searlsite but that the converse is not true. Loughlinite at Westvaco is seen to replace dolomite-quartz layers. Milton (1977) refers to these minerals as widespread but nowhere abundant.

The primary report on searlsite is given in Fahey and Axelrod (1950) wherein they report it occurring in oil shale with shortite and pyrite. Leucosphenite was first reported from the Green River Formation in the Uinta Basin (Milton, 1953) but was eventually found in Wyoming as well (Milton, 1957) at several localities. Its associations throughout the formation vary from basin to basin. In Wyoming it is found in the saline zone of the Wilkins Peak member associated with mackelveyite, labuntsovite, searlsite and "other typical minerals of the Green River Formation" (Bradley and Eugster, 1969). In Pabst and Milton (1972) it is found in rosettes near veins of shortite and loughlinite with fine ground pyrite.

Labuntsovite is first reported in Milton et al. (1958) from the Westvaco mine. It occurs there in both oil shale and trona beds in association with trona, searlsite, leucosphenite, loughlinite, shortite, barytocalcite, witherite, dolomite, calcite and bradleyite. It is also reported in tuff beds within the Green River Formation (Milton et al., 1960). Leucosphenite and labuntsovite are both restricted to a few known localities.

The only pyroxene to be found thusfar in the Green River beds is acmite while Mg-riebeckite is the only known authigenic amphibole. Acmite has been found in close association with shortite, northupite and barytocalcite occurring in well-crystallized blue-green prisms. Mg-riebeckite has been found as secondary rims on detrital hornblende in tuff beds (Milton, 1957). The occurrence of authegenic biotite has been mentioned in assocation with mackelveyite.

Both K-spar and albite are widespread. Smith and Trudell (1968) report the occurrence of both feldspars in 85-95% of the samples examined from a core hole in their study. K-spar is also present as a devitrification product in tuff beds where it occurs both euhedrally and as overgrowths on pyrogenic plagioclase (Surdam and Parker, 1972). Iijima and Hay (1968) report that "authigenic albite and less commonly K-feldspar are major constituents in some tuffs of the lower 60 feet of the Laney Shale Member and the upper 40 feet of the Tipton Shale Member..." Moore (1950) reports authigenic albite in oil shale as well.

Analcime is "by far the most widespread and abundant of the silicates..." (Milton et al., 1960) and its presence has been known since the earliest studies of the Green River Formation (Bradley, 1928). Although it occurs in tuffs as an alteration product, it is also found in beds several feet thick in shale, siltstone and sandstone.

Clinoptilolite and mordenite are both found in the tuffaceous rocks of the Tipton Member as devitrification and hydration products. Their occurrence is limited strictly to these rocks.

Sulfate minerals found in the Green River Formation are invariably products of weathering. Small amounts of celestite and gypsum have been reported (Milton, 1971) in outcrop. No primary sulfates have been reported from core samples in Wyoming.

Fluorapatite, uraniferous fluorapatite and collophane are reported in the Wyoming Green River Formation. The occurrences of these minerals are restricted but locally abundant. Fluorapatite has been found as small crystals in association with trona whereas the uraniferous deposits are generally massively bedded (Milton and Eugster, 1959; Love, 1964). Collophane occurs as organic debris and in fossils.

Organic constituents of the Green River Formation in Wyoming include gilsonite, uintahite, utahite, tabbyite, ozokerite, ingramite, albertite, coal, abelsonite and kerogen. These constituents can occur in cross-cutting seams, as matrix material with entrained minerals or as inclusions in mineral grains.

MINERALOGY OF THE UINTA BASIN

The Green River Formation in the Uinta Basin has been subdivided into different members in varying ways by different workers. This is easily understandable in light of the complex facies changes across the basin (Figure 141). The generalized stratigraphy given in Figure 142 will be used here.

For the purposes of the general lithologic description, we will adopt the nomenclature of Cashion (1959). This study was carried out at the Naval Oil Shale Reserve No. 2 in the south-central part of the Uinta Basin. Cashion subdivides the Green River Formation into three members, the lowermost Douglas Creek Member, the Parachute Creek Member and the uppermost Evacuation Creek Member.

The Douglas Creek Member consists mainly of sandstones and siltstones, shales, and oolitic limestones. The uppermost portion of this member is dominated by marlstones and oil shales.

The Parachute Creek Member in this portion of the Uinta Basin is composed of marlstones, siltstones, sandstones and oil shale. This member contains most of the oil shale reserves in the Uinta Basin.

The Evacuation Creek Member in this area consists of sandstones, siltstones, marlstones and several oil shale beds. All three members have infrequent tuff beds interbedded.

The siltstones, sandstones, marlstones and oil shales of the Green River Formation in the Uinta Basin are lacustial deposits laid down during the Eocene in what Bradley (1929b) terms Lake Uinta. This body of water was located "South of the Uinta Mountains, in Utah and Colorado..." and was "...a single large body of water..." which "...occupied the Uinta and Piceance Creek Basins during the greater part of the Green River epoch." Bradley states that it also seems probable that Eocene Uinta Lake was divided into two or possibly three lakes at certain stages of low-water level. Additionally, he feels that a case can be made for a connection between Lake Gosiute to the north and Uinta Lake "at a low place in the rim of northwestern Colorado, at the east end of the Uinta Mountains, between Cross and Juniper Mountains..." This area today is underlain by a northward trending spur of Green River beds which would appear to almost connect the Sand Wash and Piceance Basins (see Figure 136).

The depositional history of Lake Uinta as described by Bradley (1931) is quite similar to that of Lake Gosiute, already discussed. In the earliest stages of its existence Bradley feels that Lake Uinta was "large, shallow, relatively stable, and entirely fresh." After this initial stable phase and for the remainder of its lifetime, it was subject to fluctuating water levels and variations in discharge ability. During the middle phase of its existence, the lake, at times, grew deep enough to become stratified, allowing various types of deposits to accumulate. During the later stages Bradley feels that conditions became less favorable for aquatic growth and the concentration of total dissolved salts increased. After this period, a brief reversion to the original fresh-water conditions occurred during which marlstones and sandstones were again laid lown. A final diastrophic event which increased the discharge of sand to the basin heralded the end of the Green River epoch as the lake was filled in.

A list of the minerals found in the Green River Formation of the Uinta Basin is given in Table 67. As the mode of occurrence of many of these minerals is the same as that already described for the Green River-Washakie complex, only those minerals which do not appear in Wyoming or whose associations and mode of occurrence are drastically different in Utah will be discussed here.

Smith and Robb (1966) report the presense of ankerite in the Mahogony Zone oil shales in both the Uinta and Piceance Basins. In this X-ray diffraction study, careful distinction between dolomite and the iron substituted isomorph ankerite was made on the basis of the d-spacing for the 104 reflection which is consistently larger in ankerite (~2.89-2.90Å) than in dolomite (~2.885-2.886Å) they suggest that all Mahogany Zone "dolomites" are actually ankerite.

Nahcolite is present in the Uinta Basin in considerably greater abundance than in Wyoming. Pabst (1973) reports nahcolite occurring in a brown marlstone with kerogen, eitelite, trona, shortite, northupite and Mg-riebeckite in Duchesne County. Milton et al. (1955a) report it with garrelsite, shortite, searlsite and wurtzite in Uintah County. The other occurrences (Milton et al., 1960a and Chao et al., 1961) are in oil shales with the additional association of reedmergnerite, analcite, acmite and leucosphenite, and dolomite, quartz, burbankite, barytocalcite, calcite, pyrite and neighborite in the same counties. In Milton et al. (1960a), nahcolite is reported as "abundant."

Magnesite is reported in beds a foot or more thick in Milton (1971). He suggests possible misidentification in this case as magnesite is so seemingly sparse throughout the rest of the Green River Formation. Bradley (1929b) reports grains of magnesium carbonate as occurring abundantly in all the varied rocks he investigated in this report.

The occurrence of eitelite is first mentioned in passing in Milton et al. (1954a), Milton et al. (1955b) and Milton et al. (1960a). The definitive paper on eitelite (Pabst, 1973) was not published until some time later. Associations in the earlier paper of Milton et al. (1955b) include reedmergnerite, leucosphenite, shortite, searlsite and crocidolite (fibrous riebeckite). Pabst (1973) places eitelite in a marlstone (Milton's sample was from a core cutting) occurring in association with trona, nahcolite, shortite, northupite and Mg-riebeckite.

Apophyllite is mentioned in Bradley (1931) as occurring in association with analcite, however, neither Milton and Eugster (1959) nor Milton (1977) mentions its occurrence. One is left to wonder whether Milton had reason to believe that the reported apophyllite had been misidentified.

Reedmergnerite, garrelsite and elpidite have been reported only in Utah.

The occurrence of reedmergnerite, a boron analog of albite, is reported in Milton et al. (1954a, 1955b and 1960a). It has been found in oil shales with eitelite, shortite, nahcolite, searlsite, leucosphenite, acmite, analcite and Mg-riebeckite. Crystallographically oriented fluid inclusions were commonly seen in the occurrences reported here. In Milton et al. (1960b) suggestion is made that the restricted occurrence of reedmergnerite is related to the Duchesne fault zone which it lies adjacent to in Duchesne County.

Garrelsite, also unique to the Uinta Basin, is found in dolomitic marlstone with quartz, calcite, nahcolite, wurtzite, pyrite, barytocalcite, burbankite, and neighborite. Acmite is also listed as an associate mineral in Milton et al. (1960b).

Elpidite, a zirconium bearing silicate, is reported in Milton et al. (1960b) as being extremely rare. It has been found associated with nahcolite, barytocalcite and neighborite in a dolomitic marlstone. Although Milton reports elpidite as the only zirconium bearing mineral in the Green River Formation, Bradley (1931) reports zircon as appearing as well. In this context Milton probably means that elpidite is the only authigenic zirconium bearing mineral since Bradley's zircon is surely detrital.

Magnesioarfvedsonite is reported in Milton et al. (1974) where it is reputed to occur in two distinct parageneses. The first of these occurrences is as blue overgrowths on detrital pyrogenic hornblende in the more sandy beds of the Green River Formation while the second and more frequent occurrence is in oil shale as asbestiform aggregates in close association with dolomite, silica and organic material. Milton additionally states in this paper that due to the close similarity between the X-ray diffraction patterns of the fibrous Utah magnesioarfvedsonite and magnesioriebeckite, Green River amphiboles previously reported as magnesioriebeckite may actually be magnesioarfvedsonite.

Finally, it should be mentioned that the habit of leucosphenite in Utah is quite distinctly different from that found in Wyoming. Leucosphenites from Utah occurs in oil shale and is commonly associated with shortite and analcime. Other associates in Utah are reedmergnerite, eitelite, searlsite, nahcolite, acmite, crocidolite, riebeckite, dolomite, calcite, quartz and albite. Inclusions of organic material oriented into hourglass patterns are common in Utah. This habit is not found in Wyoming where the leucosphenite occurs in sheaves or rosettes associated mainly with shortite and loughlinite.

The remaining minerals in Table 68 occur in the same general associations as those discussed in Wyoming. Abundances may, however, be different, as in the case of trona which is much less abundant in Utah than in Wyoming.

MINERALOGY OF THE GREEN RIVER FORMATION IN THE PICEANCE BASIN, COLORADO

The Green River Formation in the Piceance Basin of northwestern Colorado is generally subdivided into three members. Nomenclature of these members in this basin, like the Uinta Basin, has changed with time; hence, many of the older papers referenced here will name members which do not appear in recent diagrammatic stratigraphic sections. The Evacuation Creek Member, noted previously in the Uinta Basin, has been absorbed into the overlying Uinta Formation since the work of Cashion and Donnel (1974) and, hence, will not be seen in the diagrammatic stratigraphic section shown in Figure 143.

The members shown in Figure 143 include the lowermost Douglas Creek Member, which is stratigraphically equivalent to the Anvil Points Member in parts of the basin, the Garden Gulch Member, which in places is time-equivalent to the underlying and adjacent Douglas Creek and Anvil Points, and the uppermost Parachute Creek Member, host to the rich oil shales of the basin.

Together these units form a complexly interfingered series of sandstones, siltstones, mudstones, shales, oil shales, limestones, marlstones and evaporites with occasional tuff beds.

From the work of Bradley (1931), it is clear that the deposits in the Piceance Basin were also laid down beneath the waters of Eocene Uinta Lake, whose history has already been described. Douglas Creek Arch undoubtedly formed a barrier to communication between the Uinta and Piceance basins during periods of low water in the history of Lake Uinta, thus it is not surprising that the beds of the Green River Formation in the Piceance Basin are mineralogically distinct from those of the Uinta Basin.

Generally speaking, the evaporites (halite and the sodium carbonates) were laid down during dry periods in the deepest parts of the section of Lake Uinta, which occupied the Piceance Basin. During wetter periods the marlstone and organic-rich oil shales accumulated.

Minerals found in the beds of the Green River Formation in the Piceance Basin are listed in Table 68. The distinguishing feature of the Piceance Basin is its relatively simple mineralogy in comparison to the Uinta and Green River-Washakie Basins. The Green River beds in the Piceance Basin have been extensively characterized due to the rapid development of oil shale industries seeking to mine in the area. This is especially true of the Parachute Creek Member, which contains the Mahogany zone oil shales, the main oil shale ore of the basin. A report on all the studies carried out on the mineralogy of the oil shales of the Piceance Basin alone would form a document of formidable size. Hence, we will report here on all known mineral occurrences without specific reference to all documents which may report the presence of that mineral.

Reduced sulfur bearing species present include native sulfur, pyrite, pyrrhotite, and zinc sulfide (reported as wurtzite in one case). Of these, pyrite, pyrrhotite and wurtzite are ubiquitous, though only present in small, widely disseminated amounts. Marcasite can probably be found by detailed and careful inspection of weathered outcrops, but its occurrence is always secondary. Milton (1971) notes that it has been found in weathered shale in Utah.

Halides whose presence has been documented include cryolite, fluorite and halite. Smith and Milton (1966) briefly mention the occurrence of cryolite in reference to Figure 2-D of that paper on dawsonite. Milton (1971) and Milton (1977) both mention thinly bedded and lensed cryolite in Colorado, but no further elaboration is given. Desborough et al. (1974) report both cryolite and fluorite in the rich oil shales of the Mahogany zone as tiny, disseminated grains. Thus, it would appear that cryolite has formed in two modes in the Piceance Basin; massive, but thinly bedded and widely disseminated as tiny single crystals.

Additional reports of fluorite include Smith and Milton (1966), who mention it in passing as being associated with dawsonite. Robb and Smith (1974) mention fluorite as an accessory found in their study of the Mahogany zone. Robb et al. (1978) report fluorite from two different coreholes, again within the Mahogany zone, and Giaque et al. (1981) report a single occurrence in one of the two cores examined from NOSR No. 1 in the southeast corner of the basin.

Halite is the most abundant mineral of this group. It is ubiquitously present in the saline facies of the Parachute Creek Member of the Green River Formation in the depositional center of the Piceance Basin, where it occurs massively bedded with nahcolite. Though not explicitly stated in Robb et al. (1978), halite detected in the cores examined in this study is probably also massive rather than disseminated. Samples which were shown to contain halite by X-ray diffraction were estimated at 50% halite by volume in this study.

Since quartz and chalcedony are ubiquitous, their occurrence will not be documented further here.

Milton et al. (1975) reports the presence of nordstrandite in dolomitic marlstones and oil shales in Rio Blanco County. This exceedingly rare mineral was found in veinlets and thin fissure fillings as white platy or fibrous aggregates. Its occurrence in this fashion suggests that it is not primary to the deposit (authigenic) but probably a secondary mineralization. Milton et al. (1975), however, do not necessarily subscribe to this view. Suggestion is made in this paper that it is perhaps nordstrandite which is responsible for the "excess alumina" problem in Green River oil shale analyses. If this is the case, one would expect that more careful analysis of cores would yield the discovery of many more occurrences of nordstrandite than have thus far been observed.

Nahcolite is ubiquitous in the lower units of the Parachute Creek Member in the Piceance Basin where it is associated with halite. According to Dyni (1974), nahcolite occurs as "(1) nonbedded crystalline aggregates scattered through oil shale, (2) laterally continuous units of fine-grained crystals disseminated in oil shale, (3) brown microcrystalline beds, and (4) white coarse-grained beds." The amount of nahcolite present in the Piceance Basin is far in excess of the amounts found in any of the other basins and, in fact, is the largest known concentration of nahcolite in the world. This resource was undoubtedly much larger in the past, as the strata immediately overlying the lower saline zone show unmistakable solution cavities (the "leached zone") which were at one time occupied by the soluble salts found lower in the section.

Wegscheiderite has been reported occurring in association with halite in the Piceance Basin. Its occurrence is, thus far, sporadic but consistent in the saline facies of the Parachute Creek Member.

Robb and Smith (1974) report the existence of "ferroan" scattered throughout the Colorado Core-hole No. 1 in the northern part of the basin. They verify the existence of both end members (magnesite-siderite) and the complete range of compositions in-between. Highest concentrations are reported in the saline zone. In another later study (Robb et al., 1978), similar results are reported.

The occurrences of siderite is abundantly documented in the oil shale of the Parachute Creek Member. Desborough and Pitman (1974) report it as occurring in "elliptical-shaped masses as large as 200 μm in length," and also "as small grains interlocking with calcite, dolomite, and ankerite." Desborough et al. (1974) report siderite in the principal mineral fractions of four core holes examined. Robb et al. (1978) report the presence of a magnesian siderite while Dean et al. (1981) simply report siderite as present in "greater than trace amounts" in homogenized splits from Parachute Creek and Garden Gulch Members. At N.O.S.R. No. 1 Giaque et al. (1981) show Mg-siderite as ubiquitous throughout the cores examined. Judging from the frequency with which siderite is encountered in the Piceance Basin, we feel it is reasonable to promote siderite from Milton's 1977 classification of "few known localities, nowhere abundant" to "ubiquitous," at least in the Piceance Basin.

The presence of aragonite in Mahogany zone oil shales as an authigenic constituent is explored in depth in Smith and Robb (1974). Its occurrence is ubiquitous in fossil shells throughout the formation, but it is only known to be authigenic in Colorado and possibly Wyoming.

Smith and Robb (1966) performed a detailed study of the occurrence of ankerite in the Mahogany zone. Desborough and Pitman (1974) report than Ca-ankerite is one of the most abundant Ca-Fe-Mg carbonates in the rich oil shales of the Piceance Basin.

Though dawsonite is listed as ubiquitous in Table 68, the reader should realize that this is true only in the Piceance Basin and that despite its abundance there, it is not found in any of the other depositional basins of the Green River Formation. Discussions of the geochemistry and occurrence of dawsonite are given in Smith and Milton (1966) and Beard et al. (1974) where mention is made of the inversely related abundances of quartz and dawsonite.

The sparse occurrence of barytocalcite, northupite and norsethite in association with the saline minerals of the Parachute Creek Member is reported in Robb et al. (1978). Smith and Milton (1966) also mention barytocalcite occurring in association with dawsonite in oil shale. Milton (1971) mentions the occurrence of burkeite in Colorado but no primary reference is given.

Clays reported to be present in Piceance Basin include kaolinite, illite, montmorillonite and halloysite. Other sheet silicates include chlorite, biotite and muscovite.

Illite is reported so frequently as to be considered ubiquitous. Kaolinite and halloysite are reported only once in Robb et al. (1978), as is montmorillonite in Trudell et al. (1970). Saether et al. (1981) report a strong correlation between fluorine concentrations and illite concentrations, suggesting that illite is the mineralogical residence of fluorine in the Mahogany zone. This is in contrast to the popularly held belief that fluorine is most frequently found in the more common halides fluorite, cryolite and fluorapatite.

The occurrences of biotite mentioned in Brobst and Tucker (1973) were reported for different tuff beds within the Parachute Creek Member and are not authigenic to the formation as a whole.

Searlsite has been reported in oil shale occurring in association with dawsonite and acmite (Smith and Milton, 1966) and in the saline zone of the Parachute Creek Member in relatively small amounts (Robb et al., 1978).

Additional zeolites, besides the abundant analcime, include less abundant harmotome-wellsite and natrolite.

Sulfate minerals reported as secondary alterations of pyrite and other sulfides include gypsum, szomolnokite, starkeyite, bloedite and siderotil. Barite is reported in Milton and Eugster (1959) but no mode of occurrence or primary reference is cited. Both barite and burkeite are thought to be primary authigenic mineralization.

Robb et al. (1978) report the occurrence of apatite in seven samples from cores across the depositional center of Piceance Basin whereas Robb & Smith (1974) report a single occurrence between the blue and orange markers in the Garden Gulch Member.

In conclusion, it should be noted that although the mineral occurrences noted here may seem exhaustive, it is quite likely that further careful examination of ores from all three basins will probably yield even more new minerals and mineral occurrences. There is no reason to assume that all the minerals which might be found in the Green River Formation actually have been at this point in time.

The locations of all studies referenced in this section are given in Figures 144-146 which provide the geographic settings for mineralogical work done to date in the Green River Formation. The numbers in parentheses following citations in the reference section are keyed to map locations.

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SECTION 3

GROUND WATER CHEMISTRY OF PICEANCE BASIN

This section describes the major types of chemical reactions occurring in the aquifers of the Piceance Basin with consideration given to the specific mineral assemblages. An excellent paper by Robson & Saulnier of the U.S. Geological Survey (USGS) provided the background, and virtually all of this section is taken from their paper (Robson and Saulnier, 1980).

The concentration of dissolved solids in the aquifers of the Piceance Basin varies over 2 orders of magnitude with values of 400 mg/l at the margins of the basin and up to 40,000 mg/l in the North Central part of the basin (Robson and Saulnier, 1980). Along with these lateral changes, there are also changes in concentration with depth (Robson and Saulnier, 1980). These changes in water quality include an increase in dissolved-solids concentration, a change in water type from a mixed cation bicarbonate water to a sodium bicarbonate type, oxidation and reduction of sulfur species, and relatively large increases in certain trace constituents such as strontium and fluoride (Robson and Saulnier, 1980). Robson and Saulnier state that these changes reflect the geochemical environment through which the groundwater flows and that the magnitude of the changes is affected by the type and concentration of soluble minerals present in the aquifers, the type of clay minerals and the amount of organic material present in the aquifers, and finally, the flow path of the water through the aquifers (Robson and Saulnier, 1980).

In the highland recharge areas it is seen that sandstones and siltstones of the Uinta Formation and marlstones of the Parachute Creek member crop out (Robson and Saulnier, 1980). Here, the soil cover is thin and snowmelt often infiltrates directly into the weathered bedrock before moving to unweathered bedrock (Robson and Saulnier, 1980). "The infiltrating water carries dissolved atmospheric gases and soluble minerals from weathered and unweathered surfaces into the upper aquifer" (Robson and Saulnier, 1980). Robson and Saulnier estimate that total dissolved solids (TDS) in this recharge area range from 450-800 mg/l. Carbon dioxide, CO_2, which is present in the recharge water as carbonic acid, H_2CO_3, increases the solubility of the carbonate cements present in the sandstones and the carbonate minerals present in the marlstones (Robson and Saulnier, 1980). The recharge water is observed to vary from a calcium-magnesium bicarbonate type to a mixed cation bicarbonate type (Robson and Saulnier, 1980). The recharge water is usually oxidizing, but reducing conditions exist in deeper zones as indicated by the presence of hydrogen sulfide, H_2S, gas in water from springs from deep sources and wells producing water from the upper part of the Parachute Creek member (Robson and Saulnier, 1980).

"As the groundwater of the upper aquifer flows from the recharge areas, the TDS concentration increases and the water changes to a sodium bicarbonate, $NaHCO_3$, type" (Robson and Saulnier, 1980). Large increases in TDS concentrations occur in the Uinta Formation where concentrations of two to three times that of the recharge zone are observed. Also, near the base of the upper part of the Parachute Creek member, TDS concentrations are up to ten times that of the recharge water. The principal source of this increase is upward flow of water with a high dissolved solids concentration from the lower aquifer to the upper aquifer. Upward flows also probably account for the larger dissolved solids concentrations near Tract C-b and in the north-central discharge areas of the basin.

The lower aquifer is observed to have higher dissolved solids concentrations than the upper. Robson and Saulnier state that these increases occur in three different ways. The first is by dissolution of the host marlstones as water moves through the aquifer. The second is due to permeable zones which laterally abut impermeable sections of the saline zone toward the central part of the basin. It is known that the configuration of the edges of the saline zone is highly irregular which results in local restrictions to horizontal and vertical flow. This restriction creates zones of almost stagnant groundwater which slowly dissolves saline minerals from the host rock. Finally, water moving through fractures and solution openings in the lower part of the Parachute Creek member contact sodium chloride and sodium bicarbonate salts in the aquifer. The dissolution of soluble minerals helps to produce water with dissolved solids concentrations over 30,000 mg/l.

In an earlier study, Saulnier found that dissolution is presently most active along the edges of the main body of the saline zone (Saulnier, 1978). Also, major fractures penetrate this section and allow circulating groundwater to contact the soluble salts. This phenomenon is displayed in a west-northwest trending zone of fracturing along the northern margin of the basin (Robson and Saulnier, 1980). Here, fractures allow saline water to move from the lower to the upper aquifer, thereby increasing the dissolved-solids concentration in the upper aquifer.

The principal chemical reactions occurring in these aquifers are dissolution, precipitation, ion exchange, and oxidation-reduction.

Various dissolution reactions occur at different points along the groundwater flow path. Mineralogic analyses of oil shale from the Green River Formation indicates that 43% of the marlstone is composed of calcite and dolomite (Yen and Garian, 1976). Calcite and dolomite are present as cements in the sandstones and siltstones of the Uinta Formation. Analyses performed in the recharge zones where marlstone is exposed indicates that calcite and dolomite are going into solution. Calcium concentrations are usually between 50 to 100 mg/l and are double the magnesium concentrations. Toward the center of the basin, other dissolution reactions predominate. These involve highly soluble nahcolite and halite which are found in the saline zone. This zone has very small permeability and dissolution occurs only when fractures, wells, or adjacent dissolution have exposed the minerals to water. Tests of specific conductance of water from wells near the perimeter of the saline zone indicates that large-scale dissolution occurs near the northern margin of the basin and along the edges of the saline zone. Dissolution of these salts is a contributing factor in the change of water from a mixed cation bicarbonate type to a sodium bicarbonate type.

Precipitation reactions occur throughout the Piceance Basin. The most common of these is the precipitation of calcite:

$$Ca^{++} + 2HCO_3^- \rightleftarrows CaCO_3 + H_2CO_3$$

The high bicarbonate concentrations in these waters is the driving force of this reaction.

Ions adsorbed on colloidal particles are held by forces that range from weak to very strong, depending on the kind of colloid and the kind of ion (Krauskopf, 1979). In general, the attachment is weak enough so that the ions are easily replaceable by others (Krauskopf, 1979). If a colloid with one type of ion adsorbed on its particles is added to an electrolyte solution containing different ions, some of the original ions will be set free in the solution and some of the new ions will be adsorbed in their place. This phenomenon is called ion exchange. Ion exchange is not limited to colloids, but may be applied also to the substitution of one ion for another in crystals, on surfaces, or in particles of any dimension. Robson and Saulnier report that although the changing of water from a mixed cation bicarbonate type to a sodium bicarbonate type occurs in both aquifers, the change is more pronounced and occurs in shorter lateral and vertical distances in the Parachute Creek member. Besides the dissolution of nahcolite, ion exchange is a significant factor. The dolomitic marlstones of the Parachute Creek member contain significant amounts of clay minerals which have surfaces where ion exchange reactions can take place. These clay minerals include smectite, illite, chlorite, and kaolinite. A progression of clay types occur from the basin margins to the basin center. Illite is known to be the most common clay mineral of the Piceance Basin.

The ion exchange reaction can be characterized as follows:

$$Ca^{++} + Na_2X \rightarrow CaX + 2Na^{+}$$

X indicates an exchange site on a clay mineral

Ion exchange involving dolomite could potentially contribute to the observed magnesium enrichment in these waters. The following generalized reaction scheme illustrates this:

$$CaMg(CO_3)_2 + CaX \rightarrow Na_2X + Mg^{++}$$

$$MgX + 2Na^{+} \rightarrow Na_2X + Mg^{++}$$

This could lead to the observed precipitation of low Mg calcite and relative Mg enrichment in the water.

It was mentioned earlier that oxidizing conditions exist in the Uinta Formation due to the availability of oxidized water entering this system as precipitation recharge. Sulfur is present as the sulfate ion, SO_4^{--}, in the Uinta Formation. Concentrations can exceed 500 mg/l. Where areas of upward water movement exist, reduced sulfur species migrating into the Uinta Formation are oxidized to sulfate. In areas where the upward movement of sulfur is not possible, the source of sulfate ion in the Uinta Formations is not known. It has been observed that gypsum has never been recorded in recharge areas but only in discharge areas of the Uinta Formation. In the upper parts of the Willow Creek Drainage Basin, springs bring water containing hydrogen sulfide gas to the surface from below the Uinta Formation. In this part of the recharge area such upward leakage along fractures may provide the source of sulfate for the Uinta Formation. Furthermore, in the Parachute Creek member, primary and secondary pyrite minerals of the organic rich marlstones may provide a sulfur source when exposed to the oxidized water of the recharge areas.

It has been observed that water from the organic rich marlstones of the Parachute Creek member frequently contain hydrogen sulfide gas and smaller sulfate concentrations than that found in the Uinta Formation. Sulfate concentrations of less than 10 mg/l are common in the lower aquifer. Robson and Saulnier report that during the drilling of 24 test holes in 1975-76, hydrogen sulfide gas was released as the drill penetrated the Parachute Creek member. As mentioned earlier, the source of sulfur in the Parachute Creek member is uncertain but the organic material present here helps to maintain a reducing environment. Sulfide production can occur by the following generalized reaction:

$$\text{Organic material} + SO_4^{--} \rightarrow H_2S + \text{carbonate species}$$

Pyrite, which is commonly found in small concentrations in the Parachute Creek member, is slightly soluble in warm water and can contribute small amounts of hydrogen sulfide in a reducing environment by the following reaction:

$$FeS_2 + 4H^+ + 2e^- \rightarrow 2H_2S + Fe^{++}$$

"Secondary pyrite forms when dissolved iron which went into solution in the recharge areas precipitates out of solution in the discharge areas."

"The product of all these major reaction types is a sodium bicarbonate water with oxidized sulfur species in the Uinta Formation and reduced sulfur species in the Parachute Creek member. Carbonate species and total carbon dioxide are produced by atmospheric introduction by recharge, the reduction of sulfur species, and the dissolution of the carbonate minerals, calcite, dolomite, and nahcolite. Carbonate species are removed from the system in the northern part of the basin by calcite precipitation. Large sodium concentrations are produced by ion exchange and nahcolite and halite dissolution" (Robson and Saulnier, 1980).

Robson and Saulnier also report on trace constituents found in these aquifers. Trace constituents, which are reported as being present in less than significant concentrations, include copper, beryllium, cadmium, lead, mercury, manganese, molybdenum, selenium, and zinc. The authors do not indicate their criterion for specifying what a significant concentration is. Trace constituents which are listed as being found in concentrations high enough to warrant further discussion include arsenic, barium, boron, fluoride, iron, lithium, and strontium.

The arsenic concentrations in Piceance Basin groundwater usually do not exceed 50 micrograms per liter. Concentrations between 10 to 50 micrograms per liter are common in water from wells in the Parachute Creek member in the area between Piceance Creek and Dry Fork.

Barium concentrations larger than 500 micrograms per liter were found in wells of the lower aquifer with the largest concentrations in the northern part of the basin. Concentrations are found to be less than 500 micrograms per liter in the upper aquifer. Barium is probably controlled by the solubility of barite ($BaSO_4$).

"Boron concentrations of 5,000 micrograms per liter are common in the lower aquifer but less common in the upper aquifer" (Robson and Saulnier, 1980). These concentrations are most common in the upper part of the basin where brines occur.

The distribution of fluoride in the Piceance Basin is largely controlled by the solubility of fluorite, CaF_2. Reported concentrations of fluoride are 1.1 mg/l in the Uinta Formation, 7.1 mg/l in the upper part of the Parachute Creek member, and up to 22 mg/l in the lower part of the Parachute Creek member. Robson and Saulnier explain that contributing factors to these high concentrations are the reduction of calcium concentrations due to ion exchange and calcite precipitation.

Iron concentrations of 300 micrograms per liter are common in the upper aquifer. "The sandstones and siltstones of the Uinta Formation have ironstone concretions throughout" (Robson and Saulnier, 1980). "The Parachute Creek member contains variable amounts of authigenic pyrite" (Robson and Saulnier, 1980). In the recharge areas and in the warm bicarbonate water of the lower aquifer, pyrite can dissociate to form ferrous ions, Fe^{++} in solution or the ferrous ions can combine with carbonate to form siderite, $FeCO_3$, and ferroan, $[(Mg,Fe)CO_3]$.

Lithium concentrations are found to be greater than 100 micrograms per liter in brines. The largest concentrations are found in the central part of the basin.

Strontium is a significant trace constituent of the upper aquifer, particularly in the Uinta Formation. Robson and Saulnier report that strontium containing minerals are probably being dissolved in the circulating groundwater. Geochemical computer calculations show that the water is supersaturated with respect to strontianite, $SrSO_4$. The supersaturation indicates a very slow precipitation reaction.

Summaries of detailed chemical analyses were obtained from the area oil shale office, USGS, in Grand Junction, Colorado for Tract C-b. These analyses include both major and minor components and cover the period from October 1974 to May 1980. Data for 14 wells of the upper aquifer and 16 wells of the lower aquifer were obtained. Table 69 presents a list of the well names, their location by latitude and longitude, and the aquifer which was sampled. Tables 70 through 86 are selected examples of chemical analyses for the upper and lower aquifers of Tract C-b. These analyses are shown for qualitative purposes only to illustrate major differences between the aquifers. These analyses were not subjected to any quality assurance reviews such as checking cation-anion balances and thus their inclusion here is for illustrative purposes only.

The data shows that the major ionic species include Na^+, Ca^{++}, Mg^{++}, K^+, SO_4^{--}, Cl^-, HCO_3^-, CO_3^{--}, and SiO_2. In addition to these, fluoride and strontium levels are high relative to other trace constituents. For a quick comparison of the levels of these species, from Tables 70 through 86, refer to Table 87. The data from these selected analyses show levels of TDS in the upper aquifer ranging from 540 mg/l to 1,741 mg/l and in the lower aquifer from 748 mg/l to 15,870 mg/l. Sodium concentrations range from 140 mg/l to 760 mg/l in the upper aquifer and 650 mg/l to 6,140 mg/l in the lower aquifer. Calcium concentrations range from 5 mg/l to 92 mg/l in the upper aquifer and from 4 mg/l to 10 mg/l in the lower aquifer. Magnesium ranges from 3 mg/l to 133 mg/l in the upper aquifer and from 2 mg/l to 10 mg/l in the lower aquifer. Potassium concentrations are generally low in the upper aquifer with concentrations of less than 1 mg/l up to 2.6 mg/l. In the lower aquifer, the concentration range is 3.7 mg/l to 34 mg/l. Sulfate ion concentrations vary greatly in both aquifers. In the upper aquifer the range is from 4 mg/l to 497 mg/l and in the lower aquifer from 7 mg/l to 313 mg/l. Chloride concentrations are fairly consistent in the upper aquifer ranging from 7 mg/l to 17 mg/l. In the lower aquifer the range is very great, 3 mg/l to

3,280 mg/l. The higher concentrations in the lower aquifer are probably caused by contact of the groundwater with halite. Bicarbonate and carbonate ion concentrations are also lower in the upper aquifer than the lower. HCO_3^- ranges from 340 mg/l to 1,780 mg/l in the upper aquifer and from 722 mg/l to 4,300 mg/l in the lower aquifer. CO_3^{--} ranges from 3.3 mg/l to 42 mg/l in the upper aquifer and from 14 mg/l to 288 mg/l in the lower aquifer. The higher concentration of carbonate species in the lower aquifer are probably due to contact of the groundwater with nahcolite. Fluoride concentrations in these aquifers are very interesting. The analyses of the upper aquifer range from 0.3 mg/l to 23 mg/l. Concentrations in the lower aquifer range from 17 mg/l to 28 mg/l. On the basis of these analyses fluoride would be considered a major ionic species of the lower aquifer. Silica concentrations are both similar and consistent in each aquifer ranging from 11 mg/l to 30 mg/l in the upper aquifer and from 14 mg/l to 19 mg/l in the lower aquifer. Strontium concentrations vary from 0.2 mg/l up to 5 mg/l in the upper aquifer and from 0.2 mg/l to 1.7 mg/l in the lower aquifer. Regarding other trace elements of interest, boron concentrations are variable and are above 1 mg/l in several analyses. Well WY17 had a reported concentration of 9.0 mg/l. Arsenic concentrations are always below 0.1 mg/l and usually average between 0.05 to 0.1 mg/l. Lithium concentrations are usually reported as below 0.5 mg/l, and mercury concentrations are always less than 1 microgram per liter. Barium concentrations are generally reported below 0.1 mg/l. An anomaly exists at well WY52, however, with a high concentration of 6.0 mg/l reported. Measurements of pH show that these waters are slightly alkaline with values averaging 8.7.

It was emphasized earlier that these selected analyses are displayed only for qualitative purposes to show characteristics and differences between the two aquifers. The computer printout of data from the area oil shale office does not provide any information on analytical methods or quality control/quality assurance methods employed by the laboratory. This information should be known if the data is going to be used for purposes of constructing a geochemical model. Some generalities can be made, however. As Robson and Saulnier's model suggests, the concentrations of TDS, sodium, and carbonate species is, generally, higher in the lower aquifer than the upper. Also, calcium concentrations drop in the lower aquifer with the result that this aquifer can be characterized as a sodium bicarbonate water. The concentrations of the selected trace substituents named by Robson and Saulnier warrant further investigation.

Tables 70 through 86 show only selected analyses on given dates. A check of the computer printout of all analyses for these wells revealed that the consistency analysis through time for wells of the upper aquifer was fairly reasonable except for wells WX55 and WX63. Bicarbonate analyses for well WX55 varied from 420 mg/l to 1,100 mg/l and calcium concentrations varied from 6.1 mg/l to 50 mg/l. Calcium concentrations in well WX63 varied from 3.4 mg/l to 78 mg/l. Much greater variations in time, however, are seen in some wells of the lower aquifer. Well WY52 showed a TDS concentration of 15,870 mg/l in October 1976 and only 1,900 mg/l in December 1979. Tables 83 and 84 show the discrepancies of other analyses between these two reporting periods for well WY52. Chloride concentrations, for example, varied from 3,280 mg/l down to 20 mg/l. Chloride concentrations are also seen to vary from 3.6 mg/l to 200 mg/l during the reporting period for well WY54. Well WY91 shows variations for several species through time. At this time it is not known if these variations are a result of sampling method, analytical method, well recompletion, or in fact reflect the actual water quality on these different dates. The variations between water quality of wells within either the upper or lower aquifer are at times quite large. It is not known at this point if this is a reflection of different mineralogy at different well sites or some sampling or analytical error. Subsequent mineralogical analyses and field testing of water quality should help to clarify this.

In summary, this set of water quality analyses provides a reasonably good first look at the water quality of these aquifers and an indication of specific changes in terms of ionic species from well to well.

The water quality of Tract C-b has been emphasized thus far. For purposes of comparison, Tables 88, 89, 90 and 91 list analyses at Tract C-a. The concentrations listed are averages for several analyses.

TRACE ELEMENTS IN THE GREEN RIVER FORMATION OF PICEANCE BASIN

A knowledge of the trace element distribution is important so that leachability can be appropriately modeled. Many trace elements exhibit varying levels of toxicity even at very low concentrations. Table 92 lists levels of trace elements in Green River oil shale as reported by the Laramie Energy Research Center and by DRI (Baughman, 1978). A 1977 report by TRW Environmental Engineering Division and DRI notes that relative to average rocks, shale contains much higher levels of selenium and arsenic, and moderately higher levels of cobalt, nickel, chromium, zirconium, and manganese (TRW/DRI, 1977). Table 93 contains the results of a study by the Rio Blanco Oil Shale Company for maximum and minimum concentrations of cadmium, antimony, arsenic, mercury, selenium, fluoride, and boron in fresh and spent shale from 8 different core holes.

A knowledge of the specific mineral phases of the trace elements in oil shale is necessary so that their solubility characteristics can be modeled. Unfortunately, the information on this is incomplete at present. A 1976 paper by Desborough, Pitman, and Huffman lists what is currently known in this area and their work will be discussed here (Desborough, Pitman and Huffman, 1976). Lithium was found at concentrations between 35 to 208 ppm, but the mineralogic residence is uncertain. Boron was found in concentrations between 30 to 300 ppm and the mineralogic residence was listed as probably being potassium feldspar. Fluorine concentrations were found to range between 700 to 2,100 ppm and the mineralogic residences are fluorite and cryolite. Titanium concentrations range from 700 to 2,000 ppm but the residence was not reported. Chromium concentrations range from 20 to 70 ppm and the residence for this element is also not reported. Vanadium concentrations were found to range from 100 to 200 ppm and it is suggested that this element resides in the organic matter. Manganese concentrations range from 181 to 273 ppm and the residences are Ferroan dolomite, siderite, and magnesium-siderite. Cobalt concentrations were found to range from 5 to 20 ppm, nickel between 20 to 40 ppm, and copper between 33 to 114 ppm. All of these probably substitute for iron in pyrite. Zinc was found in concentrations between 50 to 110 ppm. The residence of this element is ZnS, but it was uncertain whether the phase represents wurtzite or sphalerite. Arsenic ranges in concentration from 25 to 75 ppm and the mineralogic residence is probably in pyrite. Selenium was found in concentrations between 0.1 to 3 ppm. Because of the low concentration, the mineralogical residence would be difficult to establish but it was suggested that selenium would substitute for sulfur in sulfides and perhaps even form a discrete iron selenide. Strontium was found in concentrations between 50 and 700 ppm. The mineralogic residence was not reported. Zirconium ranges in concentration between 20 to 70 ppm and the residence is detrital or pyrogenic zircon. Molybdenum concentrations range from 7 to 40 ppm. Correlations exist between molybdenum and sulfur as a sulfide but this is still uncertain. Cadmium concentrations are very low and range from 0.6 to 1.2 ppm. Cadmium is known to substitute for zinc in zinc sulfide. Antimony concentrations are also low, ranging from 1 to 6 ppm, and the residence is unknown. Barium is found in concentrations ranging from 200 to 1,200 ppm but the residence is uncertain. Mercury ranges in concentration from 0.07 to 2.9 ppm but the residence is unknown. Finally, uranium is found in concentrations between 4.21 to 8.1 ppm but the mineralogic residence is unknown.

MODIFIED IN SITU TECHNOLOGY

This section discusses modified in situ (MIS) technology with major emphasis on listing different process control options which may affect leaching and water quality. The actual effects of these variables on leachate quality will be discussed in subsequent sections of this paper.

The MIS process as developed by Occidental Research Corporation consists of two basic steps (McCarthy and Cha, 1976). The first involves forming the in situ retort by removing about 15 to 20% of the oil shale deposit and expanding the remaining shale into the void volume. The second step is retorting the rubblized oil shale in place. The heat required for pyrolysis is supplied by either external or internal means and the volatilized oil is condensed and collected by means of a sump below the retort and pumped to the surface (Amy, 1978). The shale oil is in the form of condensable hydrocarbon vapors which is cooled to produce a semi-viscous liquid. Along with this, noncondensable vapors such as methane, CH_4, and ethane, H_3C-CH_3, are produced along with other hydrocarbons and organic compounds which exit with the off-gas. A considerable volume of retort water is also collected with the oil. The retort water comes from the liberation of free and bound water from the oil shale matrix, the combustion of hydrocarbons, the dehydration of various oxygen-containing compounds, and the recombination of H^+ and OH^- ions which are produced during pyrolysis. The composition of retort water will be described in detail later on in this paper. The size of one of these retorts will be 50 meters by 50 meters and extend through almost the entire thickness of the oil shale layer.

Pyrolysis is defined as thermal decomposition in the absence of oxygen. As already mentioned, pyrolysis in an in situ retort is supplied by external or internal means. Use of an external heat source requires the pumping of a hot inert gas such as nitrogen through the retort (Amy, 1978). As the pyrolysis zone moves, a zone of spent shale containing organic residue is left behind. When this alternative is used, reducing conditions exist throughout the retort. Use of an internal heat source implies the combustion of residual organics on the shale as the heat source for pyrolysis. The shale is initially ignited with propane, and air is then continuously supplied to the retort. The result is the formation of a pyrolysis zone and a combustion zone. The pyrolysis zone moves in front of the combustion zone leaving behind some organic matter which serves as fuel for the combustion zone. Behind the combustion zone is the spent shale. In this type of retort both oxidizing and reducing conditions exist at the same time, but for convenience the overall environment of the retort is defined as being oxidizing. Some of the residual carbon from this process still remains on the spent shale. The retorting variables are summarized in Table 94. These variables can affect the nature of the spent shale and these effects will be described in subsequent sections.

The rubblization of the oil shale is accomplished by blasting with explosives. As can be expected, a wide range of particle sizes can be produced. The size of the particles will have an effect on the reaction mechanisms of pyrolysis. For "small particles," the rate of chemical reactions governs the overall process, but for "large particles" the transfer of mass and heat governs the process (McCarthy and Cha, 1976). The rate of combustion of the residual carbon is controlled by the diffusion of oxygen. Ideally, the rubblized shale will have a uniform particle size distribution. A uniform packing will produce the highest yields of oil (Simon, 1979). A heterogeneous bed will result in uneven flow of combustion gas and a resultant incomplete pyrolysis.

J.H. Campbell and A.K. Burnham of the Lawrence Livermore Laboratory have prepared a model of the reaction kinetics for oil shale retorting (Campbell and Burnham, 1980). The kinetic expressions which they developed are focused on carbonate mineral reactions, residual carbon gasification, and pyrolysis.

At the temperatures of a modified in situ retort carbonate minerals such as calcite and dolomite decompose to oxides. These reactions are highly endothermic and therefore contribute to the overall heat balance in a retort.

Carbonate decomposition can be expressed as an equilibrium reaction controlled by carbon dioxide pressure at the reaction interface.

$$MCO_3 \underset{K_{-1}}{\overset{K_1}{\rightleftarrows}} MO + CO_2 \qquad \langle 1 \rangle$$

MCO_3 = a carbonate mineral

MO = The corresponding oxide

CO_2 = carbon dioxide

K_1 = reaction rate constant for the forward reaction

K_{-1} = reaction rate constant for the reverse reaction

The equilibrium constant, K_{eq}, is therefore:

$$K_{eq} = K_1/K_{-1} = \frac{A_{MO}\ P_{CO_2}}{A_{MCO_3}} \qquad \text{<2>}$$

A_{MO} = activity of MO

A_{MCO_3} = activity of MCO_3

P_{CO_3} = pressure of CO_2

The rate of the carbonate reaction is expressed as:

$$\frac{dMCO_3}{dt} = K_1\ (MCO_3)\ (1 - \frac{P_{CO_2}}{K_{eq}}) \qquad \text{<3>}$$

t = time

(MCO_3) = mass concentration of carbonates

$K_1 = A \exp\left(\frac{-E_A}{RT}\right)$

A = the preexponential factor, a term independent of temperature

E_A = activation energy

R = gas constant

T = absolute temperature

Campbell and Burnham reformulated reaction <3> by monitoring the rate of mass loss under linear heating conditions (Campbell and Burnham, 1980). The following expression was derived:

$$dM_L/dT = \frac{A}{H_R} \quad \text{Exp}\ \frac{-E_A}{RT} \quad (M_L - M_{L\infty})(1 - \frac{P_{CO_2}}{Be^{-F/T}})$$

$H_R = \frac{dT}{dt}$

M_L = mass loss

$M_{L\infty}$ = total mass loss at completion of reaction

K_{eq} is expressed in the equivalent form:

$$K_{eq} = \frac{A_1}{A_{-1}} \text{ Exp } (- \frac{\Delta EA}{RT})$$

$$= B \; e^{-F/T} \qquad \langle 6 \rangle$$

if the pressure of carbon dioxide is zero, equation 5 can be simplified to the following form (Campbell and Burnham, 1980):

$$\frac{dM_L}{dT} = \frac{AM_{L\infty}}{H_R} \text{ Exp } \frac{-E_A}{RT} - \frac{ART^2}{E_A H_R} \text{ Exp}(\frac{-E_A}{RT}) \qquad \langle 7 \rangle$$

E_A and A can be derived from experimental data.

The next parameter to be described is residual carbon gasification, that is, reactions between carbon dioxide and carbon, and steam and carbon. For simplicity, Campbell and Burnham assumed that the reaction rate of the steam-char reaction was first order in C, the mass concentration of carbon. However, for their experiments, they found that the actual rate is more closely approximated by the sum of two parallel first order reactions (Campbell and Burnham, 1980):

$$- \frac{1}{C_o} \frac{dc}{dt} = M_A R_A + M_B R_B \qquad \langle 8 \rangle$$

c = mass of residual organic carbon

C_o = initial mass of residual organic carbon

M_A = mass fraction of carbon consumed by first gasification reaction

M_B = mass fraction of carbon consumed by second gasification reaction

R_A, R_B = corresponding reaction rates (sec -1)

Under linear heating conditions, R_A and R_B are given by the general first order, non-isothermal rate expression (Campbell and Burnham, 1980):

$$R_i \cong A_i \text{ Exp } (- \frac{E_i}{RT} - \frac{A_i RT^2}{E_i \; H_R} \text{ Exp } \frac{-E_i}{RT}) \qquad \langle 9 \rangle$$

In general, the rate constant for carbon gasification is given by (Campbell and Burnham, 1980):

$$K = \frac{K_X P_R}{1+K_Y P_R + K_Z P_P} \qquad \text{<10>}$$

K_X, K_Y, K_Z = empirical rate constants

P_R = partial pressure of reactant gas (CO or H_2)

For pyrolysis reactions, the rate of evolution of oil or gas species during the decomposition of kerogen can be described by the following expression, assuming that the process is first order (Campbell and Burnham, 1980):

$$\frac{dC}{dT} = \frac{AC\infty}{H_R} \text{Exp} \left(\frac{E_A}{RT} - \frac{A}{H_R} \int_0^T \text{Exp} \frac{-E_A}{R_T} dT\right) \qquad \text{<11>}$$

C = pyrolysis product

$C\infty$ = total quantity of pyrolysis product evolved

Campbell and Burnham point out that this equation has a major shortcoming in that it utilizes a single value for activation energy and preexponential factor. They report that it is more realistic to expect that the evolution of products originates from a variety of chemically non-equivalent sources. Therefore, more than one constant is required. Campbell and Burnham report that a model to account for this phenomenon was developed by Anthony and Howard (Anthony and Howard, 1976). This model describes the evolution of products by a series of parallel first order rate processes which are described by a single rate constant, K_N (Campbell and Burnham, 1980). They handled the problem of how to treat activation energy by assuming that since the rate constants differ only in activation energy and that the number of parallel reactions is very large, then the activation energy can be represented by a distribution function, $D(E_A)$. Anthony and Howard's equation is:

$$\frac{dC}{dT} = \frac{AC\infty}{H_R} \int_0^\infty \text{Exp} \frac{-E_A}{RT} - \frac{A}{H_R} \int_0^T \text{Exp} \frac{-E_A}{RT} \, dT \;\; D(E_A) dE_A \qquad \text{<12>}$$

where

$$\int_0^\infty D(E_A) \, dE_A = 1 \qquad \text{<13>}$$

Anthony and Howard assume that $D(E_A)$ is represented by a Gaussian distribution with a mean activation energy E_o and standard deviation (Campbell and Burnham, 1980):

$$D(E_A) = \frac{1}{6\sqrt{2\pi}} \cdot \mathrm{Exp}\, \frac{-(E_A - E_o)^2}{2\ G^2} \qquad \langle 14 \rangle$$

Equation 13 is used by measuring the rate of product evolution vs temperature while heating the sample at a constant rate. The equation is then fitted to the data using A, E_o, and G as parameters.

The above equations apply to either an in situ or surface retort. The equations have been used successfully to model a retort. Campbell and Burnham point out that the equations are useful only for numerical or engineering modeling and that the true chemistry going on is undoubtedly more complicated than these first order reactions would imply.

This section will conclude with a discussion of a computer simulation model, also prepared by Lawrence Livermore Laboratory by Robert Braun, which predicts optimum combinations of variables for maximum effectiveness of oil shale retorting (Braun, 1979). This model takes into account a variety of reactions. Within the shale particles, the reactions considered are the release of bound water, the pyrolysis of kerogen, the coking of liquid oil, the pyrolysis of char, the decomposition of carbonate minerals, and the reaction of carbon with carbon dioxide, oxygen, and water. The chemical reactions considered in the gas stream include the combustion of oil, the combustion of H_2, CH_4, CH_x, and CO_1 and the water-gas shift. The composition of the bulk gas stream is therefore described by N_2, O_2, CO_2, CO, H_2, CH_4, CH_x, H_2O, and oil vapor. The shale composition at each point of the retort is described by kerogen, organic carbon, organic hydrogen, CO_2-A, CO_2-B, and water. CO_2-A refers to carbonates which decompose at relatively lower temperatures such as dolomite. CO_2-B refers to carbonates which decompose at higher temperatures such as calcite. The physical processes which are considered are axial convective transport of heat and mass, axial dispersive transport of heat, convective-limited heat transfer between the gas stream and the shale particles, and water evaporation and condensation. The kinetics used in this model are the same as previously described.

The first retorting option discussed by Braun is in situ retorting with 100% air. Many undesirable effects occur with this option. A major problem exists in that the retorting temperature becomes too high, greater than 1,000°C. The shale may partially melt and interfere with gas flow (Braun, 1979). Another aspect that is unfavorable is the extremely wide thermal profiles associated with this method. This results in a wasteful storage of energy within the retort and may possibly have serious implications for wall stability and later cool-down of the spent retorts. The oil yield with this method also has to be considered. A considerable portion of shale oil can be destroyed by combustion with oxygen. Braun's model shows that early in the retort, most of the inlet oxygen is consumed by oil combustion and much of the carbon in the spent shale is unavailable to oxygen because of the long diffusion paths in the large shale particles. Later in the retort, the residual carbon becomes more available to oxygen because of the longer residence time of the shale particles at elevated temperatures. This longer residence time also causes more of the carbon to be converted to carbon monoxide by reacting with carbon dioxide, and the carbon monoxide is then burned in the gas stream which further decreases the available oxygen for oil combustion. However, Braun reports that even at a depth of 25 meters, as much as 45% of the oxygen is still available for oil combustion. One way around this problem is to recycle some of the off-gas to the inlet air. This recycle gas provides an alternative fuel to oil. A resultant reduction in oil combustion results. This is obtained, however, at the expense of drastically reducing the retorting rate for a given total inlet-gas flux. The use of recycle gas also causes special environmental problems which will be discussed later.

Braun goes on to report that the use of air and steam is a promising alternative to air and recycle gas. The maximum temperature of the retort stays below 1,000°C while using this method and the energy stored within the retort, in terms of heated shale, is less than half that for an input of 100% of air. Furthermore, the loss in oil yield is reduced by using a steam air input. As in the case of the 100% air mode, most of the oxygen at the start of the retort is consumed by oil combustion. However, it decreases rapidly with depth and levels off at 25% at a depth of 26 meters as compared with 40% for the straight air input. This decrease in oil combustion, however, is not attributed to a larger amount of burning of the carbon residue. Only 15% of the inlet oxygen is directly consumed by the carbon residue as opposed to 40% for the 100% mode. The carbon is therefore less accessible to direct burning because of the lower oxygen content in the bulk gas. Braun explains that the principal reason for the observed lower oil combustion is the greater amount of carbon monoxide and hydrogen present, each of which account for 25 to 30% consumption of the inlet oxygen as steady state is approached. Carbon monoxide and hydrogen are formed from the carbon steam reaction and, in turn, are released from the oil shale particles and burned in the bulk gas. Therefore, the use of steam increases the indirect utilization of the carbon fuel which results in the lower combustion of oil. The above considerations apply for an air steam mixture of 50 and 50%.

The use of a higher percentage of steam, for example up to 75%, can also be considered. However, there is a danger here of encountering, within the retort, a zone barren of organic matter which could extinguish the combustion wave.

The use of 100% steam is also possible, which would eliminate oil loss from combustion. However, the steam would have to be superheated and this would therefore be a very expensive way to generate heat. A further disadvantage of hot-gas (noncombustion) retorting is the high degree of oil coking. This is due to the fact that the heating rate in the temperature range of kerogen decomposition is slow and there is available time for the liquid oil to undergo coking within the shale particles before being volatilized and driven out. This process gets progressively worse with increasing depth in the retort because the shale heating rate gradually decreases. At a depth of 25 meters, the oil loss from coking is 20%. Braun goes on to discuss the effect of steam content on oil yield and retorting rate. He notes that the oil yield rises sharply at steam contents greater than 25% because of the decrease of oil combustion and reaches a maximum between 75% and 100%. As the steam content approaches 100% the oil yield drops rapidly because of the previously described coking phenomenon. An optimum steam content may be 75%, but this may prove to be too high because of economic factors. Too high of a steam content is also undesirable because the retorting rate decreases due to the lower oxygen flux, the primary determinant of the retorting rate. He adds, however, that for the various steam-air mixtures, the retorting rate does not decrease as fast as the oxygen flux. A 50% decrease in oxygen in going from zero to a 50% steam content only causes a 30% decrease in retorting rate. This is caused by two factors. The greater amount of chemical reactions between the carbon residue and steam results in a lower fuel density in the retort, because some of the fuel escapes from the retort as product gases, hydrogen, and carbon monoxide. This decrease in fuel density allows a more rapid advancement of the combustion front.

The flow rate of inlet gas is another variable which can be used to control a retort. Lower flow rates result in a lower maximum temperature of the retort and in higher oil yields.

Table 95 lists the principal organic oil shale products and by-products.

MINERAL REACTIONS DURING RETORTING

This section describes some of the mineral reactions which may occur during an MIS retort. This information is included because of the effects these synthesized minerals will have on water quality. The reactions which will be most carefully considered are the carbonate decomposition reactions and the formation of silicates. These reactions are not only interesting from an environmental viewpoint but also for engineering considerations as they are highly endothermic and affect the overall heat balance of the retort.

J.P. Fox (Fox, 1979) reports the major findings of Campbell and Taylor (Campbell and Taylor, 1978; Campbell, 1978) in a report on water quality from in situ leachates. The unbalanced reactions which occur are as follows (Campbell, 1978):

$$\mathrm{Ca(MgxFe_{1-x})(CO_3)_2} \xrightarrow{600^\circ\mathrm{C}} \mathrm{Fe_2O_3 + MgO + CaCO_3 + CO_2}$$

$$\mathrm{CaCO_3} \xrightarrow{700\text{-}800^\circ\mathrm{C}} \mathrm{CaO + CO_2}$$

$$\mathrm{CaO + SiO_2} \xrightarrow{700\text{-}800^\circ\mathrm{C}} \mathrm{Ca_N\ Si_M\ O_{(N+2M)}}$$

$$\mathrm{CaCO_3 + SiO_2} \xrightarrow{\text{Greater than } 800^\circ\mathrm{C}} \mathrm{Cax\ Si_yO_{(Cx+2y)} + CO_2}$$

The calcium silicates which form are gehlenites, akermanites, melilites, and diopside (Campbell and Taylor, 1978). The silicates are insoluble, which may suggest that total dissolved solids from an MIS retort may be low, but Fox points out that it is difficult to extrapolate these results to an actual retort. Campbell and Taylor's studies were performed in a laboratory, under ideal conditions, using small quantities of finely powdered shale to avoid heat and mass transfer limitations. In an actual retort, silicate formation will be limited by large particle sizes and nonuniform heating rates. Fox concludes that it is likely that only a small fraction of the carbonate minerals will be converted to insoluble silicates. She supports this statement by noting that some leaching studies for simulated spent shales subjected to temperatures greater than 800°C are not significantly different from leaching studies of shales subjected to lower temperatures. These leaching studies will be described in detail later in this paper. A summary of the reactions from above with rate equations is shown in Table 96. All of these reactions are greatly enhanced by steam (Campbell and Taylor, 1978; Burnham, Stubblefield and Campbell, 1980).

This section will conclude with a discussion of mineralogic research conducted by the Occidental Research Corporation (Kuo et al., 1979). The goals of this research were to show that previous work done on leaching from MIS spent shale have little applicability to real situations because of short retorting times (a few hours) used in the simulations. In an actual retort, the minerals will be subjected to high temperatures for two weeks or more. Occidental's position is that spent shale from an MIS retort minimizes the leaching of inorganic ions into the aquifer water. They base their conclusion on laboratory kinetic studies that consider long-term mineral transformations, leaching artificially prepared spent shale, and mineralogical characterization and leaching of spent shale cores from one of Occidental's in situ retorts. Their kinetic studies show dolomite, calcite, quartz, and other minerals leading to generally insoluble forms. These reactions are said to be promoted by extremes of time and temperature during the MIS retort, and catalysis by steam in the retort gas. They report that periclase (MgO) and lime (CaO) can be completely consumed.

The kinetic studies were accomplished by preparing pellets of shale. These pellets were prepared by compacting approximately 30-40 grams of oil shale powder in a die at 1.4×10^5 kPa. THis preparation was done to minimize the natural nonhomogeneity of oil shale and the compaction was said to restore the original grain to grain contact. The experiments were performed in furnaces at controlled temperatures and atmospheres at times ranging from one to 1,800 hours. Occidental found that at temperatures between 600-700°C both dolomite and calcite decompose completely. Dolomite decomposes to form periclase and calcite. Calcite should decompose to form lime but no lime was ever detected. They assumed that the lime reacted immediately with quartz and periclase to form various silicates. Periclase was observed to reach a maximum concentration between 530 → 650°C and then to disappear within hours at temperatures above 800°C. The concentrations of akermanite ($Ca_2MgSi_2O_7$) and diopside ($CaMgSi_2O_6$) were observed to be low at 600°C, but the level of akermanite at 760°C and after 20 hours was 60 weight percent of the spent shale. Diopside content after 100 hours and at 760°C was 7-9 weight percent. Above 900°C, the diopside concentration increases while the akermanite concentration decreases. The fate of these minerals is shown schematically in Figure 148 for an isothermal retort at 650°C under a 1% oxygen in nitrogen atmosphere for 0.5 to 264 hours. The experiments also showed that the presence of steam speeded up these reactions. Occidental also did a mineralogical analysis of spent shale from one of their MIS retorts. The results were the same as laboratory studies with akermanite and diopside the principal minerals present and no free lime or periclase detectable by x-ray analysis. This retort was said to be held at high temperatures for long periods of time. The x-ray data from these core samples is shown in Figure 149.

It is pertinent at this point in the discussion to recall the two points made by Milton concerning the temperature of formation of the vast majority of minerals in the Green River Formation and the overall chemical homogeneity. From the first point, one can safely assume that, under the conditions of MIS retorting, virtually all of the Green River minerals are well outside their conditions of stability and will react to form different minerals and possibly a glass phase. From the second point, one may safely say that the response of the mineralogical suite to MIS processing will vary despite the fact that the overall chemistry may be consistent. Although a few isolated studies on the reactions of major phases to MIS processing have been carried out, these studies by no means take into account all of the minerals known to occur within the Parachute Creek Member and, in point of fact, almost nothing is known about the relative solubilities of the less common but nonetheless important minerals.

FACTORS AFFECTING LEACHATE QUALITY AND LEACHATE STUDIES

This section will provide a review of experimental studies which deal with the leaching of inorganic and organic constituents from modified in situ spent shale. The topics which will be covered include the effects of retort gas environment and retort temperature on leachables, a discussion of laboratory models of spent shale leaching, the interaction of native groundwater with spent shale, the partitioning of major and minor species, the expected mobility of major and minor elements in the alkaline environment of spent shale, sulfur speciation, and a characterization of the movement of organic compounds from spent shale.

The oil shale of Piceance Creek is largely impermeable to water. However, the nature of the modified in situ process with partial mining, rubblization, and retorting introduces a high degree of permeability. Although the true nature of the aquifers is considerably more complex, an upper and a lower aquifer is usually defined with the organic rich Mahogany zone acting as an aquitard. This is shown in Figure 150. The leachate migration will depend on how the retort is constructed relative to the aquifers (Fox, 1979). Simply speaking, four different configurations are possible and these are shown in Figure 151 (Fox, 1979). The retort may, therefore, intersect both aquifers, only one, or neither. If both aquifers are intersected the retort can act as a conduit and transport leachates from one aquifer to another. The flow may be upward or downward depending on the head differential between the aquifers. The case of the retort not intersecting either aquifer is an unlikely configuration for the oil shale zone of Colorado.

Parker, Bethea, Guven, Gazdar, and Watts have described the mechanics of in situ leaching (Parker et al., 1977). This group noted that the spent shale must cool to below the boiling point of water to allow leaching to occur. The cooling of the shale may take years. As liquid water comes into contact with the spent shale it will be drawn into the shale by capillary forces. If a fragment of spent shale is suddenly immersed in water these capillary forces will draw water into the shale and displace gases out through the largest pores. The influx of water will displace soluble salts near the surface of the fragment to the central portion of the fragment. This will result in a displacement of soluble salts to the upper surface of the fragment where they will be more quickly leached. After the remaining pore space is filled with water, molecular diffusion will serve as a vehicle to transfer soluble material to and from the shale fragment and the groundwater.

Ionic reactions can begin after the spent shale has cooled to the point where liquid water can exist. This water contacting the spent shale may have originated from condensing steam where only the salts of the spent shale will react, or it may be the groundwater where a wide range of reactions will be possible. Major anticipated reactions include those of the lime produced from decomposition of calcite and dolomite, the precipitation of divalent cations, and alteration of the solubility of various species due to pH changes of the leachate. The environment inside a spent shale fragment will probably be very different from that of the native groundwater. As mentioned earlier, the pH of the groundwater is between 8 and 9. Parker's group points out that the pH inside a spent shale fragment could be above 12. Reactions inside a fragment could be the precipitation of calcium and magnesium carbonates and hydroxides. Therefore, spent shale may not only add certain ions to the groundwater but may also remove other ions.

The quality of the leachate from MIS spent shale will be the result of a complex series of interacting variables (Fox, 1979). The five major variables include the chemical-mineralogical characteristics of raw oil shale, the retorting conditions, the particle size distribution of the spent shale, the quality and temperature of groundwater, and the flow regime of the groundwater through the abandoned retort. The first two are considered the most important. The above considerations can be easily determined, but Fox points out that there are two other factors about which little is known. The first is that the bottom of the retort may be incompletely retorted and wet with oil and have accumulated metal species. The other factor is that gases produced during retorting may migrate out of the burn area and into an aquifer. Unfortunately, both of the above mentioned factors are poorly understood at the present time.

The water quality data from Tract C-b suggests that the mineralogy changes by location. Therefore, the inorganic leachables would be expected to vary also.

Leachate quality is highly dependent on retorting conditions with the most important parameters being temperature and composition of the input gas stream (Fox, 1979). Temperature affects mineral reactions such as carbonate decomposition, the pyrolysis of kerogen, and the possible volatilization of certain chemical species. Input gas dictates the atmosphere in which these reactions will take place. An inert gas such as nitrogen provides a reducing environment while an air or an air-stream mixture provides an oxidizing environment. Both organic and inorganic leachables will be affected by this. Furthermore, the air-recycle gas mode will cause other interactions to take place, such as adsorption onto the spent shale of the components of the recycle gas.

Amy and Thomas have reported that inert gas and air-recycle gas methods leave the highest residuals of organic leachables on the spent shale (Amy and Thomas, 1977). This occurs in the inert gas mode because no combustion of pyrolysis products takes place (Fox, 1979). In the air-recycle gas mode organics are adsorbed into the spent shale behind the reaction front. The lowest concentration of organics are found following a high temperature combustion run which does not utilize recycle gas. Here, the residual carbon is utilized as a fuel source; however, some residual carbon will remain on the spent shale (Kuo et al., 1979; Amy, 1978).

The highest concentrations of inorganic leachables are found following retorting at temperatures between 600 and 800°C (Fox, 1979). This temperature is high enough for carbonate decomposition but below that required for silication reactions. The resulting leachate will have a very high pH. In addition to this, if air is used as input gas certain metals will be oxidized producing forms which are more soluble. Dr. Willard Chappel notes that molybdenum, boron arsenic, selenium, fluoride, and lithium can be mobilized in an alkaline environment (Chappel and Klusman, 1980). Some reactions which may occur are as follows:

$$B \xrightarrow{O_2} BO_3^{---}$$

$$Mo \xrightarrow{O_2} MoO_4^{--}$$

$$Se \xrightarrow{O_2} SeO_4^{--}$$

$$As \xrightarrow{O_2} AsO_4^{---}$$

As previously described, temperatures above 800°C can provide an environment where insoluble calcium and magnesium silicates may form. An insoluble layer around the spent shale could effectively entrap many of the leachables (Fox, 1979). Recall also that a steam environment acts as a catalyst to the silication reactions and retort temperatures above 800°C are likely for MIS retorts. Conflicting comments appear in the literature regarding the extent of these silication reactions. Fox points out that laboratory studies were performed under ideal conditions using small particles which avoided heat and mass transfer limitations. Fox also points out that in the field, silication would be limited by large particle sizes and nonuniform heating rates. Occidental's position, as has already been pointed out, is that the reactions will proceed and not be kinetically limited because of the long time periods that the oil shale will be subjected to elevated temperatures (Kuo et al., 1979).

Leaching will be somewhat dependent on the spent shale surface area (Fox, 1979). This refers to both the external surface area and the internal surface areas due to pores created by kerogen removal. It has been found that spent shale of small particle size will contain higher concentrations of leachables during the initial periods of leaching because of the greater surface area. Initial leaching concentrations of particles of larger sizes are lower.

Fox points out that the chemical and physical properties of the ambient groundwater will have a large effect on the nature of the leaching. Groundwaters with high total dissolved solids and alkalinity will affect leaching by means of a high buffering capacity, by precipitation reactions involving ions originally present in the groundwater and ions leached from the spent shale, by the counter diffusion of ions originally present in the groundwater back into the shale matrix, and by ion exchange reactions. The most important physical properties include temperature and the flow regime. Solubilities of chemical species are affected by temperature, with some components being either more soluble or less soluble at higher temperatures or either more soluble or less soluble at colder temperatures. The flow regime dictates the direction and velocity of water flow which could influence the kinetics of chemical reactions, the surface renewal of groundwater at the groundwater/spent shale interface, and how the groundwater initially contacts the spent shale.

With this background information completed, this section will now present a review of studies conducted with the leaching of inorganic compounds from spent oil shale. Most of the background information for this section was obtained from Fox's review and this discussion of inorganic leachates will also be quoted from that reference. The data to be discussed are largely the result of laboratory simulations. The data is included in this report to show what types of leaching may occur from MIS spent shale and also to compare these results with the model to be completed on this project.

Several researchers have completed work on inorganic leaching. The works of G.L. Amy, H.W. Parker et al., and John Shafer were based on simulated in situ spent shales while the work of Jackson et al. was focused on field measurements of backflood waters in southwestern Wyoming (Fox, 1979). Their studies show that the principal ions in leachate are sulfate, sodium, bicarbonate, and hydroxide. Species found in lower concentrations included chloride, fluoride, lithium, molybdenum, lead, and zinc. The leachates usually had high electrical conductivity, and high pH. It was found that most constituents were leached after the passage of the first few pore volumes of water. These studies will be discussed in more detail.

Jackson's group studied leaching by groundwater of spent shale in the field at the Laramie Energy Technology Center's site 6 true in situ field experiment. The exact retorting specifications were not given, but mentioned only that "Site 6 was an unsuccessful attempt at in situ shale oil production. Conditions sufficient for retorting were maintained for an extended period, but at no time could volumes of oil as large as 1 gallon be collected from the pattern wells" (Jackson et al., 1975). What was found in this experiment was that elevated concentrations of many components persisted in the burn area for years after retorting was terminated. Leachables which were found above 1,000 mg/l included sodium, chloride, sulfate, bicarbonate, and carbonate. Calcium, magnesium, potassium, and fluoride were found at moderate levels. Also, the concentrations of calcium, magnesium, chloride, and sulfate were observed to decrease as the leachate moved through the aquifers. It was concluded that calcium and magnesium concentrations were attenuated by precipitation, and chloride and sulfate by ion exchange.

Parker's group performed one set of experiments on high and low temperature inert gas simulated retorts and subsequent leaching for 450 hours with rock springs groundwater. The oil shale used was from Colorado. Table 97 summarizes their results. Note that retorting conditions affect leachate quality. In the low temperature run calcium decreases significantly, magnesium and sodium decrease slightly, and zinc, carbonate, and iron remain about the same. For the high temperature run, carbonate, iron, and magnesium decrease significantly, sodium decreases slightly, calcium, fluoride, and zinc remain the same, and boron, copper, potassium, lithium, and pH increases. Note the very large increase in the concentration of boron. It was concluded that calcium, magnesium, carbonate, and iron concentrations were attenuated by either carbonate or hydroxide precipitation reactions and sodium was removed by ion exchange.

Fox points out that there are major differences between laboratory and field experiments which must be kept in mind when reviewing this data. During an actual retort there are gases, oils, and liquids which are produced which may contact an aquifer. This can potentially increase the concentrations of carbonate, bicarbonate, ammonia, and sulfur compounds. Fox made a comparison of Parker's and Jackson's experiments and noted that Parker recorded a decrease in carbonate concentration while Jackson recorded an increase. Also, Parker indicated that calcium and magnesium decrease during initial leaching periods while Jackson indicates that they increase. Fox explains that carbon dioxide produced during retorting can go into solution and increase the levels of carbonate species. In addition, beds of nahcolite are present in the field which further complicates the difference between a laboratory and field study. Parker's study showed a decrease in total dissolved solids while Jackson's study showed an increase. The major difference was in sodium and carbonate concentrations. Fox explained that the difference was probably due to carbon dioxide dissolution and leaching of nahcolite which led to higher observed levels in Jackson's study.

Parker did some additional simulation studies on interactions of Utah oil shale with Utah groundwater and compared the effects of retort temperature and temperature of the leachate to see how these variables affect the amount of material leached from spent shale (Parker et al., June 1978; Parker et al., Sept. 1978). A summary of these experiments from Fox's paper appears in Table 98 (Fox, 1979). The experiments were performed by placing 450 grams of crushed Utah oil shale in the Laboratory retort and operating at the temperatures and atmospheres indicated. The retort was allowed to heat to the desired temperature for a period of twelve hours and then was maintained at the temperature for 48 hours. Leaching was accomplished by placing a 67 to 86 g piece of spent shale into 200 ml of water for 21 days. The data demonstrates the very high levels of conductivity and high pH for the sample retorted at 780°C. Leaching from spent shale retorted at 1,000°C shows greatly reduced values of conductivity relative to the 780°C retort due to the silication reactions. The pH of 1,000°C spent shale leachate is still very high, which indicates that there was not enough silicon present to react with all the calcium and magnesium. The high temperature retorting had little effect on the leachability of selenium, arsenic, or fluoride but tended to enhance leaching of boron. The hydration of unconverted metal oxides is responsible for high pH and conductivity in leachates derived from shale retorted at 1,000°C.

Parker also studied the leaching from spent shale of inorganics using distilled water as leach water. The results of this work would be very hard to extrapolate to field conditions because of the unavailability in the distilled water, of ions to participate in reactions with ions from the spent shale. Parker's data showed that concentrations of calcium, iron, potassium, sodium, and strontium are higher in leachates from combustion runs rather than from inert gas runs; that the levels of lithium, strontium, and chromium in leachates derived from high temperature combustion and inert runs are much higher than from low temperature runs; that calcium concentrations are higher in high-temperature inert leachates and potassium is higher in high-temperature combustion leachates; and that the levels of magnesium are higher in leachates derived from low-temperature runs. Table 99, obtained from Reference 21 shows a comparison of leaching studies using distilled water. Table 100 shows the result of a Soxhlet extraction from Occidental's retort core 3E. Occidental also shows a comparison of the Soxhlet leaching of retorted shale with that of pilot plant samples and raw shale (Kuo et al., 1979). Refer to Table 101.

Gary Amy has conducted the most extensive study of the leaching of organic material from in situ spent shale (Amy, 1978). The study did not include characterization of the structures of organic compounds leached from spent shale but instead focused on gross organic parameters such as total organic carbon (TOC) and functional group analysis such as acid, base, and neutral fractions of leachate, organic nitrogen, and phenols. The investigations included kinetic and equilibrium batch experiments and continuous flow column experiments. The experimental variables examined in these investigations are shown in Table 102. The kinetic experiments involved placing 50 grams of spent shale in 50 ml of water for varying time periods. The goal here was to derive kinetics of organic leaching based on the previously mentioned experimental variables. The equilibrium batch experiments involved placing 50 grams of spent shale in varying amounts of water (30 to 200 ml) for 30 days. The purpose of these experiments was to obtain data for the purpose of generating equilibrium isotherms. The retorting conditions of the shale included combustion runs, combustion runs with recycle gas, and inert gas runs. The spent shale was obtained from Lawrence Livermore Laboratory's pilot scale 125-kilogram simulated in situ retort. The Fischer assay was 24 gallons per ton and the organic content of the raw shale was 10.8%. The water temperatures used in these studies were 20°C and 80°C. The low temperature was to simulate ambient groundwater conditions, and the higher temperature was to simulate water flowing through an incompletely cooled retort as water temperature in the field could approach 100°C. Both distilled water and synthetic groundwater were used in the experiments. The synthetic groundwater was prepared by mixing 6.0 grams of $NaHCO_3$, 2.0 grams of NaCl, 1.0 gram of Na_2CO_3 and 1.0 gram of Na_2SO_4 to a liter of distilled water. The continuous flow experiment involved placing spent shale in columns of varying length and allowing water to flow through at various rates. Only the condition of 20°C was examined in this experiment. Table 103 lists the retorting conditions of the spent shale and Table 104 lists the physical and chemical characteristics. The samples will hereafter be referred to as Types 1-4.

The results of the distilled water kinetic batch experiments are shown in Figures 152 through 155 and summarized in Figure 156 (Amy, 1978). As would be predicted, spent shale from a combustion run leaches the lowest amounts of organics, but even so the amount is considerable, 10 mg/l of total organic carbon. In Figure 156, note the significantly higher levels of TOC leached from a combustion-recycle gas spent shale. Note also in Figures 152-155 that more organic carbon was leached from smaller-sized particles. Note also that the greatest rate of leaching occurred on the first day.

The results of the kinetic batch experiments using distilled water at 80°C are shown in Figures 157-160 and summarized in Figure 161 These results show that elevated temperatures had little effect on Type 1 spent shale, significantly enhanced the leaching of Types 2 and 4 spent shale, and slightly inhibited the leaching of Type 3 spent shale. As before, the smaller particles leached out higher levels of TOC than larger particles. Also, as before, the rate of leaching was the greatest during the first day and decreased afterwards.

The results of the kinetic batch experiments utilizing synthetic groundwater at 20°C are shown in Figures 162-165. For comparative purposes Amy also placed the distilled water results on these graphs. The results show that groundwater slightly decreases the amount of material leached from Type 1 spent shale, enhances leaching from Type 2 spent shale, slightly inhibits leaching from Type 3 spent shale, and slightly enhanced leaching from Type 4 shale.

The results of the kinetic batch experiments utilizing synthetic groundwater at 80°C with corresponding data for distilled water are shown in Figures 166-169. Once again, the elevated temperature and use of groundwater enhanced the leaching of organics from Type 2 and Type 4 spent shale but had little effect on Types 1 and 3.

Table 105 shows the total organic material leached from the spent shale for each experimental variable after the full 30 days of leaching. This table summarizes the findings that retorting conditions, water temperature, and water quality affect the amount of organics leached from spent shale.

Amy subjected composite samples of the leachates from the above experiments to organic extractions to determine amounts of acidic, neutral, and basic functionality. Table 106 shows the results of these extractions. Note that the totals of extractibles for each spent shale type show different trends than the TOC measurements in the distilled water experiments. Amy used hexane as an extracting solvent and explained that these discrepancies are probably due to differing extraction efficiencies. The data suggests that different types of organic compounds are leached for different retorting conditions and that phenolic compounds, which would be present in the acidic fraction, might be present. The presence of phenols could cause serious water quality problems. These extractions show that a very detailed examination of the structures of these extractible organic compounds is required where individual compounds would be purified by liquid and/or gas chromatography and their structures identified by spectroscopic methods. Some of the structures of carbonaceous shale have been identified by J. Schmidt-Collérus but only an extensive field survey could accurately determine the hydrological mobility of specific compounds (Schmidt-Collérus, 1974). Tables 107 and 108 show Amy's results for organic nitrogen and phenols from composite samples.

Table 109 provides Amy's results for the equilibrium batch experiments. This investigation was performed in order to prepare equilibrium isotherms. Both Langmuir and Freundlich models were used. The equation for the Langmuir model is:

$$q = \frac{ABC}{1+AC}$$

q = mass of organic carbon remaining on the spent shale per unit mass of spent shale

C = Equilibrium TOC in leachate expressed as mg/l

A, B = constants

The equation for the Freundlich model is:

$$q = KC^{I/N}$$

K, N = constants

Amy found that at intermediate values of q and C both models fit the data. The Langmuir model is more appropriate for lower values, and the Freundlich model is more appropriate at higher values (Amy, 1978). Figures 170 and 171 show plots of these isotherms.

Amy's continuous flow column experiments were performed to simulate leaching under actual field conditions. The flow rate through these columns was set at 0.6 ml/min. This flow rate was also selected to simulate field conditions. Figures 172-175 show his results. Note that the greatest amounts of material for all four spent shale types decreases rapidly after the initial periods of leaching. This is true for both organics and inorganics as is evidenced by the conductivity measurements. Amy explains that the initial leaching of material is explained by the proximity of the material to the exterior surface of the spent shale where it is subject to eddy diffusion and the weak association with the spent shale matrix due to weak physical forces. Material leached during later time periods is due to the proximity of the material to the interior of the spent shale matrix where it must be slowly transported to the exterior by molecular diffusion or its strong physical and/or chemical association with the spent shale matrix.

Much more organic carbon was leached during the continuous flow column experiments than the batch experiments. This can be seen by examining Table 110. Table 111 shows the weight and bulk density of spent shale samples compacted into the columns. Amy notes that detectable levels of organic carbon were still observed from the columns after 96 hours of leaching. Therefore, the data in Table 110 represents the minimum potential mass of leachable organic carbon under field conditions.

The discussion that follows from Amy's paper deals with the minimum amount of organic material which can be leached from a single retort. The discussion is generally applicable to conditions in the Piceance Creek Basin. Amy initially points out that real water quality problems will be highly site-specific and dependent on stratigraphy, ambient groundwater quality, ambient geohydrology, and the proximity of in situ retorts to wells, streams, and springs. Furthermore, the water quality considerations for an entire development area must take into consideration the complex geohydraulics known to exist in the Piceance Creek Basin, the aerial extent and spacing between a large number of retorts, and the interaction of leaching phenomena among the several retorts. For this discussion then, Amy assumes a typical in situ retort to have dimensions of 50 meters in length, 50 meters in width, and 60 meters in height penetrating the entire thickness of the oil shale layer and establishing communication between the upper and lower aquifer. Another assumption is that the retort contains approximately 1.5×10^8 kg of spent shale with a bulk density of 1.0 g/cc. Amy explains that as groundwater enters a retort organic compounds will be solubilized until saturation conditions exist. Afterwards, as more water enters, saturation may not be attained until leachate nears the effluent end. Finally, after a given time, saturation conditions will exist throughout the retort. This is shown schematically in Figure 176. The retort effluent will therefore be saturated with organic compounds for a considerable time period. After this, the concentration will diminish, but a constant amount will leach due to material whose leaching is limited by internal diffusion through the porous infrastructure of the spent shale matrix. These low levels could persist for years, leading to a serious chronic problem. This phenomenon is shown schematically in Figure 177. Amy points out that the above discussion of the leaching process is qualitative and the real process depends on the dimensions of retort, the characteristics of spent shale, the ambient groundwater quality, and the geohydrologic condition. Amy goes on to estimate the minimum mass of the organic carbon which can be leached from either a Type 1 or Type 2 spent shale. These values were estimated from the equilibrium batch experiments using a shale to water ratio of 50 g/200 ml and from the continuous flow column experiments. Table 112 shows these estimates. Where two values are shown, the higher one is from the continuous flow column experiment. Table 113 gives an estimation of the saturation concentrations of organic carbon. Amy assumed that a retort will have a porosity of 50% and that the pore volume of a typical retort is 7.5 x 10^7 liters. Based on this, Table 114 provides an estimation of the minimum mass of organic carbon to be leached from a retort and Table 115 provides an estimate of how much water will be required to leach this mass. This organic mass which is leached will enter the upper aquifer and its movement will be limited by the low permeability of this aquifer. It will be many years before this organic pollution will be flushed out to the receiving streams.

A great deal of work has been conducted and is in progress to characterize the specific organic compounds resulting from oil shale wastes and effluents, but a considerable amount more needs to be done in order to fully assess the threat to human health which this type of pollution may impose (EPA, Sec. 5, 1979). One reason why a complete knowledge of organic contaminants is needed is the likely presence of polynuclear aromatic hydrocarbons and their nitrogen derivatives in the spent shale, shale oil, and retort water. Some members of this class of compounds are known to be human carcinogens (EPA, 1979). As is known from the discussion of Amy's paper, even combustion retorted spent shale will contain large amounts of leachable organic carbon. Also, as has been mentioned, portions of an MIS retort may not be completely retorted and wel with oil. This would allow leaching of all the classes of compounds listed in Table 95. An investigation of carbonaceous matter on spent oil shale at the Denver Research Institute (Schmidt-Collérus, 1974) indicates the potential seriousness of organic pollution. Known carcinogens were detected in the spent shale in levels much higher than the surrounding environment and it was shown that the inorganic salts present in leachate help to leach these compounds from the spent shale surfaces (Schmidt-Collérus, 1974). Although the amount of this material leached per given mass of spent shale is low, the magnitude of a full scale oil shale industry makes this a serious problem. Some of the compounds identified by the Denver Research Institute are displayed in Table 116. Another study on organic residues from spent oil shale was conducted at Utah State University (Maase et al., 1980). This group performed both organic and water extractions on the spent shale and gas chromatographic and thin layer separation of the leached compounds. Structures of compounds were confirmed by mass spectrometry. The spent shale studied was derived from surface retorts

(Union B, Paraho, and TOSCO II), but their results are included here because the nature of organic leachables from MIS spent shale will be similar. Table 117 lists the identified leachables from benzene extractions. The work with thin layer chromatography and GC/MS showed the presence of at least 8 polynuclear aromatic hydrocarbons. These are listed in Table 118. The presence of other polynuclear material such as benzo a and e pyrenes and perylene was indicated by gas chromatographic retention time, but insufficient mass was present for positive identification by mass spectrometry. Their water extracts also indicated that polynuclear material was leaching, but positive identification was not possible because of insufficient mass.

Another group of organic compounds with implications for human health which may be found in leachate are sulfur heterocycles. A listing of these compounds found in shale oil is presented in Table 119.

A recent study by Batelle has shown that alkyl substituted pyridines represent a class of compounds unique to shale oil and may be very useful indicator compounds for use in monitoring effluents (Riley et al., 1981). The highest concentrations where they have been found are in the retort water and shale oil. Recall that earlier in this report it was mentioned that parts of an MIS retort may be incompletely retorted and wet with oil. Leaching from this area may present a serious water quality problem. Batelle's work shows that alkylpyridines have considerable hydrologic mobility. Therefore, this class of compound may have great utility as an indicator to monitor this phenomenon.

Fox mentioned several conclusions in her review paper which are important considerations in planning environmental controls for an in situ oil shale industry (Fox, 1979). The first conclusion deals with the essential irreversibility of groundwater disruption. Fox mentions that because of the low water flow velocities in these aquifers it may take centuries for the leachate to be removed from the area and a natural equilibrium to be re-established. The degradation in water quality in the absence of the control measures may persist for centuries and the largest increases of inorganics will likely be pH, sulfate, sodium, bicarbonate, and carbonate. The largest increases in organics will likely be phenols and organic nitrogen compounds. Calcium and magnesium levels will drop due to precipitation and ion exchange reactions. Other major inorganics in leachate will be chloride, silicon, and potassium. Oil shale contains a very large variety of trace elements, all of which are likely to be in the leachate. The most important of these which should be considered for this model include arsenic, selenium, molybedenum, boron, lithium, vanadium, fluorine, chromium, zinc, nickel, beryllium, lead, mercury, and strontium. These trace elements are targeted either because of their mobility in an alkaline environment, their toxicity to human, animal, or agricultural plants, their known association with spent shale, or some combination of these factors. Arsenic poisoning in humans is the result of a cumulative effect on the entire system (EPA, Sec. 6, 1979). It can also cause dermatitis, bronchitis, and is carcinogenic to the mouth, esophagus, larynx, and bladder. Arsenic also inhibits the synthesis of adenosine-5'-triphosphate (ATP) and the thiodependent enzymes. Arsenic can be found in spent shale, retort, water, and raw shale oil. Lead accumulates in bones and soft tissue and causes reduction of brain functioning, and interferes in the synthesis of amino acids and enzymes. Lead can also cause kidney damage. Lead is primarily seen in spent shale. Vanadium inhibits the activities of certain enzymes, and adversely affects tissue oxidation. It is found in both spent shale and shale oil. Selenium is an irritant of the nose, throat, and respiratory tract. It is also associated with liver cancer, pneumonia, degradation of liver and kidney tissue, and gastrointestinal disturbance. Chromium is most toxic while in the hexavalent oxidation state. This species is considered to be a carcinogen. Chromium leaching may be serious because of the oxidizing conditions present in an MIS retort which may lead to the production of hexavalent chromium. Nickel can cause respiratory disorders including cancer. It also inhibits the activity of cytochrome oxidase, isocitrate dehydrogenase in the liver, and maleic dehydrogenase in the kidney. Nickel is found in the spent shale. Beryllium causes chemical pneumonitis, and is a potential carcinogen of the lungs and bones. Beryllium is mainly found in the spent shale. Mercury is most toxic in the plus two oxidation state where it can cause a variety of health problems. Most of the mercury will be flushed out of the retort with the off gas but the bottom portions of a retort may be enriched with condensed mercury. Since this phenomenon is at present poorly understood, the transport modeling of this element will be very difficult. Boron will be problematic mainly for plants and is easily leached from spent shale (Chappell, 1978). Fluoride causes mottling of teeth, plant damage, and calcification in humans and livestock. Molybdenum is highly toxic to livestock, but is not toxic to plants. Of all these trace elements which have been listed, W.R. Chappell lists fluorine, arsenic, boron, selenium, and molybdenum as having the most priority for study (Chappell, 1978).

Going back to Fox's conclusions on leachate problems, the large time factor for water quality degradation is continually stressed. A high level of treatment may be necessary for most uses for a long time period. Also, it will take many years for groundwater even to enter the abandoned retort after dewatering. Fox reports that the differences in hydrology between Tracts C-a and C-b are significant. For example, at Tract C-a, leachate may be released from a single retort for 1 to 6 years and this would be transported in the lower aquifer at a rate of 160 ft/yr. It would take 100 years for this to be discharged into the nearest stream. On the other hand, leachate release from the same retort at Tract C-b will occur from 6 to 54 years and will move through the upper aquifer at a rate of 20 to 30 ft/yr. It will therefore take 200 years for the leachate to be discharged into the nearest stream. Leaching can be controlled to a considerable extent by retorting at temperatures above 800°C and by using steam with the air input gas assuming that efficient and uniform combustion takes place. The result will be a leachate with a lower concentration of total dissolved solids and alkalinity. However, this will not be a suitable control for pH, fluoride, boron, and most other trace constituents. The contamination due to organics will still be a problem also. The surface streams most affected by leachate will be Piceance Creek and Yellow Creek and ultimately the Colorado River. A final problem will be that of surface retorted spent shale disposal piles. Uncontrolled leaching from these piles will almost certainly affect groundwater quality. Crushed raw oil shale is not inert either and will release certain constituents in a similar manner as spent shale. This phenomenon has been described in a recent EPA report (McWhorter, 1980).

Fox has prepared an estimate of the maximum amount of leachate leaving a retort after the passage of the first few pore volumes of water (Fox, Dec. 1980). This corresponds to the pulse front shown in Figure 178 (Fox, Dec. 1980). Fox based this work on four assumptions. These assumptions are: 1) Most leachable constituents are removed with the passage of the first 2 to 6 pore volumes of leach water. 2) The mass of material leached per unit mass of spent shale using distilled water and contact times of up to 30 days is similar to what would be leached using local groundwater and contact times greater than one year. In other words, the values summarized in the last column of Table 99 are reasonable approximations of the mass of material leached per unit mass of spent shale. 3) The leachate concentration exiting from the retort is constant. 4) The spent retort intersects a groundwater aquifer and groundwater migrates vertically through a retort. The most critical assumption according to Fox is the number of pore volumes required to remove the bulk of leachables. The available data suggests from 2 to 6 pore volumes but the required amount in a field retort may be larger due to large particle sizes of spent shale. The estimated compositions of leachate leaving an in situ retort for Tracts C-a and C-b are shown in Table 120. Fox is careful to point out that these estimates may be off by a considerable amount due to differences in laboratory simulations and an actual retort. Contact times will be vastly different as well as particle size range, groundwater temperature, and the varying quality of groundwater contacting a very large retort. Another factor is that retorting temperatures in a field retort will likely be greater than 800°C, leading to the formation of insoluble silicates. Therefore, the actual amount of leachates may be less. Ultimately, the real situation of leaching will be a virtual unknown until extensive field testing is performed.

The equation which Fox used to derive the values in Table 120 is the following:

$$\bar{C}_i = \frac{10M_i m + (Cg)_i nV}{nV}$$

$\bar{C}_i$ = average maximum concentration of ith constituent exiting the retort

M_i = mass in milligrams of ith constituent per 100 grams of spent shale (last column of Table 35)

m = mass of spent shale in a single retort, assumed to be 1.1×10^9 kg for Tract C-a and 7.5×10^8 kg for Tract C-b

V = volume of water within a single retort, assumed to be 5.0×10^8 liters for Tract C-a and 2.0×10^8 liters for Tract C-b

n = number of pore volumes (2 to 6) required to remove most of the leachables

$(Cg)_i$ = concentration of ith constituent in the groundwater

Fox points out that the accuracy of this equation is dependent on the M_i term, which is derived from leaching studies using simulated in situ spent shale.

When assessing the potential for water quality degradation in either of the oil shale lease tracts in Colorado, it is important to keep in mind the direction flow water will take if both aquifers are intersected by a retort. A 1974 USGS report shows that water will flow from the upper aquifer to the lower aquifer at Tract C-a and from the lower aquifer to the upper aquifer at Tract C-b (Weeks et al., 1974). Therefore, even if Occidental's claim that leaching from MIS retorts presents no environmental problems, water quality in the upper aquifer at Tract C-b will be degraded by upward flow from the lower aquifer. The low values in columns 6 and 7 of Table 56 are computed from the lower values of M_i from the last column of Table 35 and using 6 pore volumes of required leach water. The high values in columns 6 and 7 of Table 56 are computed by using the high values of M_i from the last column of Table 35 and using 2 pore volumes of leach water.

Fox argues that the consequences of leaching at Tract C-a will not be as great as at Tract C-b (Fox, Dec. 1980). This is because the flow is downward and the lower aquifer is not presently used because of its poor quality. Over a long time period, however, the upper aquifer will be degraded by water migrating through vertical cracks in the Mahogany zone. Water quality degradation would be a more immediate problem at Tract C-b because of the upward flow and the fact that upper aquifer water is currently used for agriculture and livestock. The upper aquifer also recharges local streams.

A conclusion which can be drawn from this section on leaching is the present state of infancy which the environmental chemistry on this subject is in. Very few studies have been done on the leaching phenomenon and these are not all in agreement and have not been subjected to adequate peer review. Furthermore, the studies have of necessity concentrated on simulations and some were based on simulated shale and distilled water which probably represents the worst possible situation. Unfortunately, the only study which examined actual field conditions was performed by Occidental at Retort 3-E (Kuo et al., 1979). Recall that Occidental's conclusion was that MIS retorting is an environmentally safe method. A critical review of their work was presented by Fox (Fox, Dec. 1980). The following is a direct excerpt from her report (Fox, Dec. 1980): "The present author is in disagreement with these conclusions.

The work by Kuo et al. did not reliably simulate field conditions and the authors did not report adequate information to evaluate discrepancies between their work and others. Under field conditions, elevated-temperature spent shales will be contacted by high TDS groundwater. Residual gases such as CO_2 and H_2S, trapped in fractures and pores, will participate in the leaching process. Thus, Kuo's work is not sufficient to conclude that there will be no environmental problem. Additional work, which must include field measurements, is required to definitively answer this question. These authors also did not report adequate information to substantiate their conclusions. Very little experimental data were reported, only conclusions from the data. No information was given on shale-water contact times, a critical variable in leaching; and no information was presented on analytical methods. This lack of adequate experimental data and a methods description, coupled with the disagreement between this work and all others completed to date, leads the present author to conclude that this work must be repeated in other laboratories and the detailed data results published in the open literature before a fair assessment can be made."

The formation of insoluble silicates during a retort is undoubted, but Occidental's contention is that the reactions are quantitative, leading to 100% completion. Even if this happened there will still be trace elements and organic compounds released from the spent shale. Field retorts will probably not always operate under optimum conditions either. Ideally, the shale will be rubblized to a uniform small particle size. Such a configuration would ensure uniform combustion and heat transfer. In actual retorts there will probably be a large heterogeniety of particle size. Combustion and heat transfer will therefore not be nearly as efficient. The nature of spent shale will be a complex function of its original mineralogy and the retort conditions. Assuming that an MIS retort will be operated in the air-steam mode, there might be vast differences in the nature of the spent shale due to possible inefficient rubblization and difficulties in controlling the combustion parameters.

ELEMENT PARTITIONING

Element partitioning, as it applies to the oil shale technology, refers to the final distribution of elements after the retorting process. The possibilities for where elements may end up include the shale oil, the off-gas, the retort water, and the spent shale. Any interest in the control of the release of elements from oil shale retorting must include a fundamental knowledge of this phenomenon. For the purposes of this project, it is important to know which elements remain with the spent shale. The most complete description of elemental partitioning to date has been written by Fox (Fox, May 1980). Fox provides a very thorough discussion of the methods and quality control used in this work. Only the major conclusions will be presented here.

The work was performed using simulated in situ conditions by means of the Laramie Energy Technology Center's controlled state retort (see Figure 179) and Lawrence Livermore Laboratory's 125 kg and 6,000 kg simulated in situ retort (see Figure 180) (Fox, May 1980). The retort operating conditions for these are given in Tables 121 and 122. These tables will be referred to in describing her results. The work at the Lawrence Livermore Laboratory on the simulated in situ retort will be given the most emphasis, because this more closely resembles field conditions.

A major consideration in understanding the partitioning phenomenon is the type of mineralogical reactions which occur during the retort. These depend heavily on retorting conditions and dictate whether an element will be volatilized to the gas stream, remain on the spent shale, or dissolve into the retort water or shale oil. The major reactions are as follows:

Carbonate Decomposition

Dolomite

$$\mathrm{Ca(Mg_x,Fe_{1-x})(CO_3)_2} \underset{(400\text{-}700^\circ\mathrm{C})}{\xrightarrow{\Delta}} \mathrm{(1-x)FeO + xMgO + CaCO_3 + CO_2}$$

Calcite

$$\mathrm{CaCO_3} \underset{(700\text{-}950^\circ\mathrm{C})}{\xrightarrow{\Delta}} \mathrm{CaO + CO_2}$$

Dawsonite

$2NaAl(OH)CO_3 \xrightarrow{\Delta} Na_2CO_3 + CO_2 + H_2O$
(270°C)

Shortite

$Na_2Ca_2(CO_3)_3 \xrightarrow{\Delta} Na_2Ca(CO_3)_2 + CaCO_3$
(470°C)

Trona

$2Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O \xrightarrow{\Delta} 3Na_2CO_3 + CO_2 + 5H_2O$
(270°C)

Silicate Decomposition

Analcime

$NaAlSi_2O_6 \cdot 2H_2O \xrightarrow{\Delta} NaAlSiO_4 + SiO_2 + 2H_2O$
(800 → 1,000°C)

Clays

$Clay \xrightarrow{\Delta} Al_2O_3 + SiO_2 + Fe_2O_3$
(>800°C)

Silicate Formation

$nCaO + mSiO_2 \xrightarrow{\Delta} Ca_nSi_mO_{(N+2M)}$
(>800°C)

Other Reactions

$2FeO + CO_2 \xrightarrow{\Delta} Fe_2O_3 + CO$

$Na_2CO_3 \xrightarrow{\Delta} Na_2O + CO_2$

Obviously, many other reactions are taking place, but to date these are the best known reactions (Fox, May 1980). Recall that calcite and dolomite decomposition as well as silicate formation are catalyzed by the presence of steam in the retorting atmosphere.

Tables 123 and 124 show the average elemental abundances for raw and spent Green River Formation shales. The reactions listed above would indicate that most of the inorganic elements will not be volatilized in a retort, and Tables 123 and 124 bear this out. Note that the abundances of most elements is 20% higher in spent shales than raw. This is because the organic fraction of oil shale, which is also about 20%, is volatilized during retorting. The elements which are not completely partitioned into the spent shale include mercury, cadmium, hydrogen, carbon, nitrogen, and sulfur. These compounds plus selenium are volatilized from the shale and are partitioned into the oil, retort water, and off-gas. A large part of the inorganic carbon is lost as CO_2 during the carbonate decomposition reactions. Other reactions of carbon including that of the char, C, and organic carbon during retorting are as follows (Fox, May 1980):

$$C + CO_2 \overset{\Delta}{\rightleftarrows} 2CO$$

$$C + O_2 \overset{\Delta}{\rightleftarrows} CO_2$$

$$C + H_2O(g) \overset{\Delta}{\rightleftarrows} CO_2 + H_2$$

$$RCOOH \overset{\Delta}{\rightarrow} RH + CO_2$$

$$\text{Organics} + O_2 \overset{\Delta}{\rightarrow} CO_2 + H_2O$$

Reactions of mercury will be discussed later.

Three groups of elements were delineated based on their percent mobility from the shale (Fox, May 1980). These groups are as follows:

% Mobility
Group 1: (10-100%) H, Hg, C, N, S, Cd
Group 2: (1-10%) Se, Ni, As, Co

Group 3: (<1%) Cr, Sb, Zn, Cm, Na,
Mo, V, Ga, Fe, Mn, V,
Ba, Dy, La, K, Mg, Sn,
Cs, Em, Hf, Rb, Ce, Sr,
Al, Ca, Sc, Ti, Yb, Th

These mobilities for both the LETC and LLL runs are shown in Table 125. Figure 181 shows the mass distribution patterns for group 1 elements from the LETC controlled state retort. Figure 182 shows the mass distribution pattern for groups 1 and 2 elements from LLL's 125 kg retort. Table 126 shows the mass distribution patterns for Group 2 elements.

Mercury is therefore the most mobile toxic trace element associated with in situ oil shale processing. Table 127 lists mercury concentrations in the various phases for all experimental retorts. Note that for the LETC runs spent shale was sampled at the top, middle, and bottom of the retort. Except for runs CS-62, CS-66, CS-69, CS-71, and CS-72, the mercury concentration is highest in the bottom than in the top and middle spent shales. This is due either to imcomplete retorting in the bottom section and/or the condensation of volatilized mercury from other sections. Also, note the difference in mercury concentration for spent shale between the LETC controlled state retort and the LLL retorts. Much more mercury is removed from the LLL runs. This is probably due to the higher temperatures used in these runs.

The description of the LETC runs in Table 121 shows that runs CS-31, CS-32, CS-37, and CS-60 are labeled as interrupted runs. In these runs, the first 7 feet of shale were retorted and then the run was stopped by rapidly cooling the retort. Therefore, the top 7 feet of the shale bed is completely retorted, the next 2 feet is partially retorted and wet with oil, and the bottom 3 feet is unheated and wet with oil. Analyses for the volatile elements along the shale bed show that mercury travels as a pulse ahead of the reaction zone. This is shown in Figures 183-186. The pulse shape is related to particle size, with the smaller particles producing taller, narrower pulses. Mercury appears to be traveling as a chromatographic wave through the retort. In these simulations there is a very uniform particle size which allows the retort to function as a chromatographic column with respect to mercury. In a field retort the particles will range in size from fines to boulders. The movement of mercury as a pulse in this environment will probably not occur.

Instead, the volatilized mercury will encounter various resistances to mass transfer and will probably condense in cool zones of the retort or in zones of inefficient retorting. Because of this behavior, the concentration of mercury in spent shale and leachate will be hard to predict.

The specific partitioning mechanisms are not at present completely understood (Fox, May 1980). The following is a summary of the types of reactions thought to occur during a retort:

Mineral Decomposition

Sulfide

$$MS(g) \overset{\Delta}{\rightleftarrows} M(g) + S(g) \tag{1}$$

Carbonate

$$MCO_3\ (s) \overset{\Delta}{\rightleftarrows} MO(s) + CO_2\ (g) \tag{2}$$

Oxide

$$MO(s) \overset{\Delta}{\rightleftarrows} M(g) + \tfrac{1}{2}O_2(g) \tag{3}$$

$$MxOy(s) \overset{\Delta}{\rightleftarrows} xM(g) + YO_2(g) \tag{4}$$

Kerogen Conversion

$$\text{Kerogen} \qquad \begin{array}{l}\text{Oil}\\ \text{Gas}\\ \text{Bitumen}\\ \text{C Residue}\end{array} \tag{5}$$

Reduction

Carbon

$$MxOy(s) + yC(s) \overset{\Delta}{\rightleftarrows} xM(g) + yCO(g) \tag{6}$$

Carbon Monoxide

$$MxOy(s) + yCO(g) \overset{\Delta}{\rightleftarrows} xM(g) + yCO_2 \tag{7}$$

Oxidation

$$xM(g) + yO_2\ (g) \overset{\Delta}{\rightleftharpoons} MxO_2y \qquad (8)$$

$$MS(s) + O_2(g) \overset{\Delta}{\rightleftharpoons} M(g) + SO_2\ (g) \qquad (9)$$

Shale-Product Interactions

Condensation

$M(g) \rightleftharpoons M(aq)$ (10)

Dissolution

$M(g) \rightleftharpoons M(aq)$ (11)

$M(g) \rightleftharpoons M(oil)$ (12)

$M(aq) \rightleftharpoons M(oil)$ (13)

Solubilization

$$MxOy(s) + yH_2O \overset{\Delta}{\rightleftharpoons} xM^{+}\ (aq) + 2yOH^{-}\ (AQ) \qquad (14)$$

$$MCO_3\ (s) + H_2O \overset{\Delta}{\rightleftharpoons} M^{++}\ (aq) + CO_3^{=}\ (aq) \qquad (15)$$

Suspension of Fines

Raw Shale
and
(Spent Shale Fines) → (oil and water) (16)

Equations 1-4 show that an element may be volatilized as a result of mineral decomposition. Equation 5 shows that mineral volatilization may occur by kerogen conversion and equations 6-7 show that mineral volatilization may occur by reduction by carbon, carbon monoxide and other species. Equations 8-9 show that volatile species may be removed from the gas stream as metal oxides, or condensed on the cool shale ahead of the reaction front by equation 10, or entrapped in the oil-water emulsion by equations 11-12, or swept out of the retort in the gas stream as gaseous or condensed species. Equations 14 and 15 show that water which condenses out of the gas stream ahead of the reaction zone may leach some constituents from the unreacted shale. Equation 13 shows the reactions occurring in the oil-water emulsion. Finally, equation 16 shows the interactions between raw and spent shale fines and the oil and retort water.

The following group 1 elements, S, N, H, and organic carbon, reside mainly in the kerogen and are therefore released during pyrolysis. Significant amounts partition to the oil and gas phase, and large amounts of H and N also partition to the retort water. The volatilization of other group 1 elements, Hg and Cd, is probably controlled by mineral decomposition and both probably exist in the raw shale as sulfides, HgS and Cds. Recall that in an MIS retort, both reducing conditions and oxidizing conditions are present. In the pyrolysis zone, which travels ahead of the combustion zone, a reducing environment is present. The combustion zone is, of course, oxidizing. Calculations worked out by Fox show that the probable reactions occurring for mercury are as follows:

Pyrolysis Zone

$$HgS + H_2 \rightleftarrows Hg(g) + H_2S(g)$$

$$HgS + CO \rightleftarrows Hg(g) + COS(g)$$

Combustion Zone

$$HgS + O_2 \rightleftarrows Hg(g) + SO_2$$

$$HgS + H_2(g) \rightleftarrows Hg(g) + H_2S(g)$$

$$HgS + C \rightleftarrows Hg(g) + CS(g)$$

Mercury may of course enter into a multitude of other reactions, including reactions with oxygen halides, and organic radicals.

Fox's work shows that the majority of the 50 elements studied are not significantly mobilized during retorting with the exception of C, H, N, S, Cd, and Hg. Tables 128-151 show the elemental abundances for the LETC and LLL runs and Tables 152-177 show the mass abundances for these same runs.

SULFUR SPECIATION

The chemistry of sulfur is of interest because of the types of reactions which it can undergo during retorting. In addition to this, ionic sulfur species which are currently not components of the aquifers will be introduced by commercial MIS retorting. These exotic species will include thiocyanate, SCN^-, thiosulfate, $S_2O_3^{--}$, and tetrathionate, $S_4O_6^{--}$ (Stuber, Leenheer and Farrier). Thiosulfate may form by the reaction of SO_2, formed in the combustion zone, with elemental sulfur (Stuber, Leenheer and Farrier). Alternatively, this may form in a reaction of H_2S with SO_2 to produce $S_2O_3^{--}$, $S_3O_6^{--}$, and S_4O_6, and $S_4O_6^{--}$ (Stuber, Leenheer and Farrier). Thiocyanate forms in a reaction of cyanide, CN^-, with elemental sulfur (Stuber, Leenheer and Farrier).

RETORT WATERS

Retort water is a by-product of any oil shale process. It was previously described as being derived from the liberation of free and bound water from the oil shale matrix, the combustion of hydrocarbons, the dehydration of various oxygen containing compounds, and the recombination of H^+ and OH^- ions which are produced during pyrolysis. In situ retorting is known to produce the greatest amounts of retort water (Fox, Dec. 1980). This is shown in Table 176 (Fox, Dec. 1980). Note that an MIS retort can produce 11.5 barrels of water for every barrel of oil produced. The in situ retort waters are brownish to yellowish in color, have a pH between 8 and 9 and have high levels of inorganic and organic constituents. Although this water is removed from the retort with the oil, and is therefore not in contact with the abandoned retort, a discussion of it is included to demonstrate the magnitude of treatment which would be required of this type of wastewater. Also, if this water were disposed of untreated, an adverse effect on groundwater could occur.

The major inorganic components of retort water include ammonia, carbonate, sodium, magnesium, calcium, bicarbonate, sulfate, and chloride ions (EPA, Sec. 6, 1979). Table 113 shows some water quality parameters of some simulated in situ retorts (Fox, Dec. 1980). A partial elemental analysis of the modified in situ Occidental retort is shown in Table 114 (Fox, Dec. 1980).

The organic components of retort water are primarily polar with the main functional group being normal carboxylic acids. Other types of functionality include phenols, ketones, pyridines, pyrroles, lutidines, anilines, amines, indoles, and quinolines (Fox, Dec. 1980). The organic carbon content of retort water can be as high as 4.2% (Riley et al., 1979).

CONCLUSION

The above report is a compilation of the general state of knowledge of environmental chemistry in oil shale research. As is evident from reading this text, there are no conclusive definitions on the leaching phenomenon from MIS spent shale. Some trends can be seen in the various investigations, but unfortunately the available data can only be classified as being in a preliminary stage. The completed investigations on inorganic leachables are not in complete agreement with one another, and there has been only one effort with organic leachables. The completed work does point out which parameters warrant further study. These have been mentioned in different parts of the report.

The major tool which will be required to complete the chemistry for this project will be a geochemical computer model which simulates mass transfer and reaction path sequences among a given mineral assemblage. Once the mineralogy of spent shale is known in detail, the geochemical computer model can predict the changes in water quality, and knowledge of hydrology can show the flow path of the leachables.

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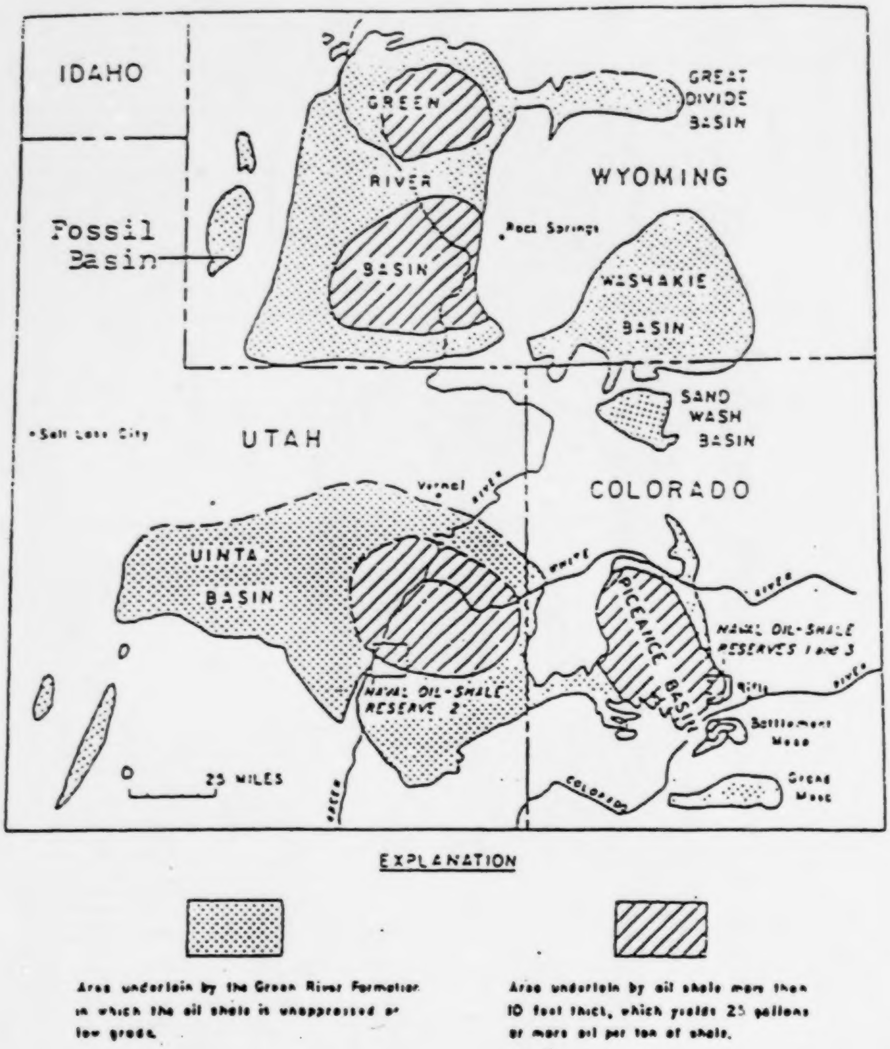
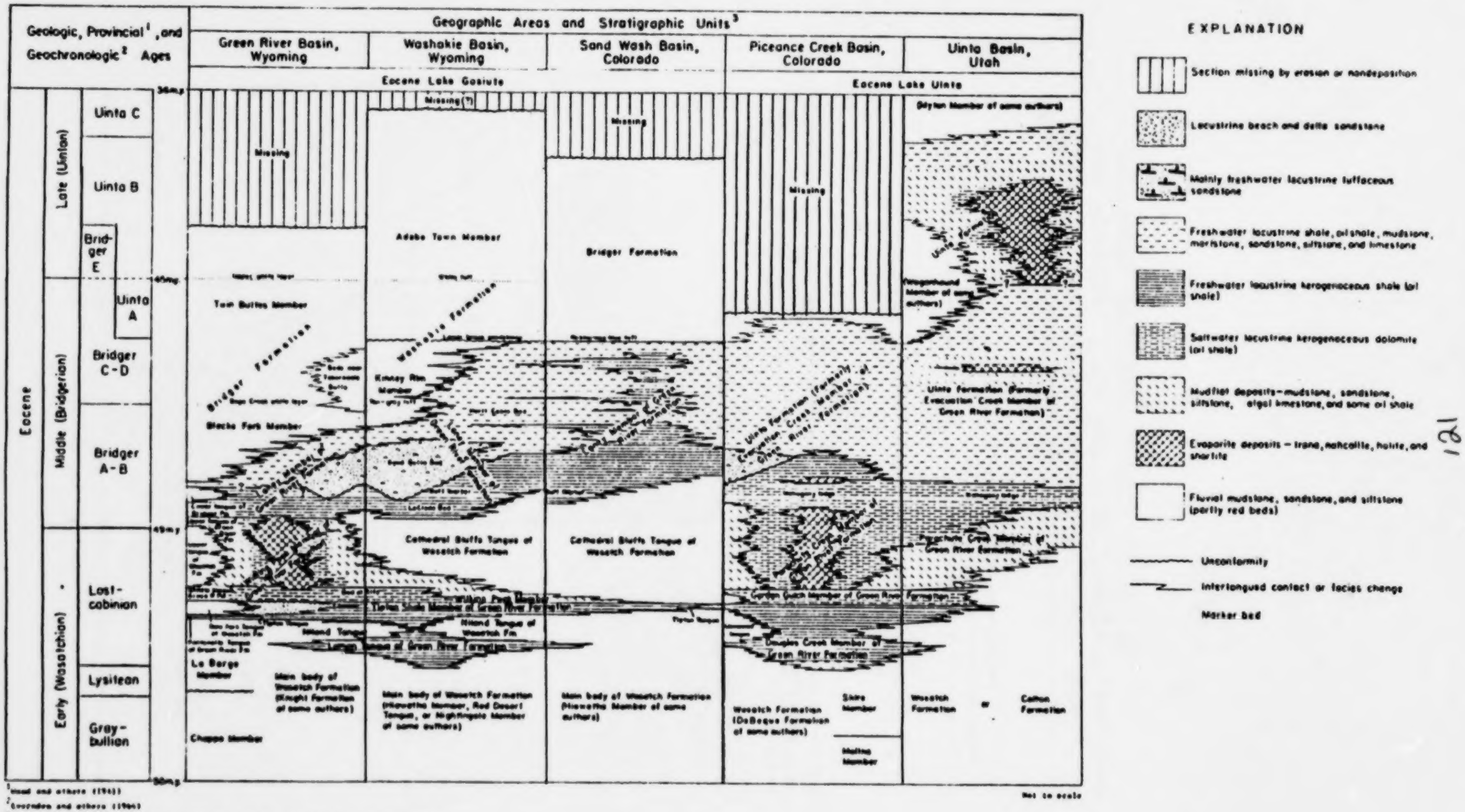
SECTION 1

HYDROLOGY FIGURES


IDAHO
WYOMING
UTAH
COLORADO
GREEN RIVER BASIN
GREAT DIVIDE BASIN
Fossil Basin
Rock Springs
WASHAKIE BASIN
SAND WASH BASIN
Salt Lake City
Vernal
UINTA BASIN
WHITE RIVER
PICEANCE BASIN
NAVAL OIL-SHALE RESERVES 1 and 3
NAVAL OIL-SHALE RESERVE 2
Rifle
Battlement Mesa
Grand Mesa
GREEN
COLORADO
0 25 MILES
EXPLANATION
Area underlain by the Green River Formation in which the oil shale is unappraised or low grade.
Area underlain by oil shale more than 10 feet thick, which yields 25 gallons or more oil per ton of shale.

Oil Shale Basins and area of occurrence of Green River formation in Colorado, Utah, and Wyoming. From Colorado Energy Resources Handbook, Colorado School of Mines.

Figure 1



[1] Wood and others (1941)

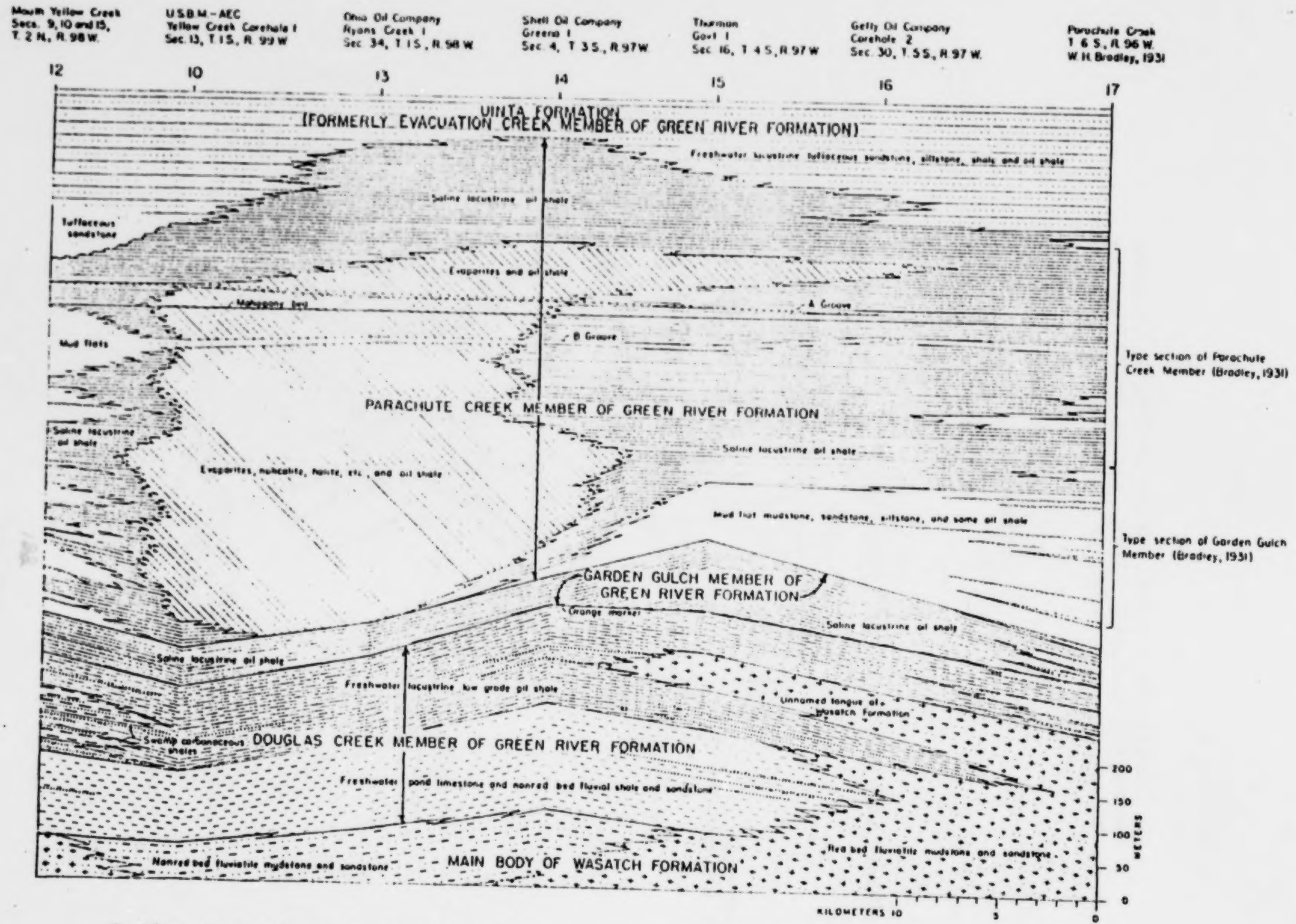
[2] Evernden and others (1964)

[3] Some of the stratigraphic units shown are not adopted by the U.S. Geological Survey

Correlations of Eocene formations in northwest Colorado, northeast Utah, and southwest Wyoming.

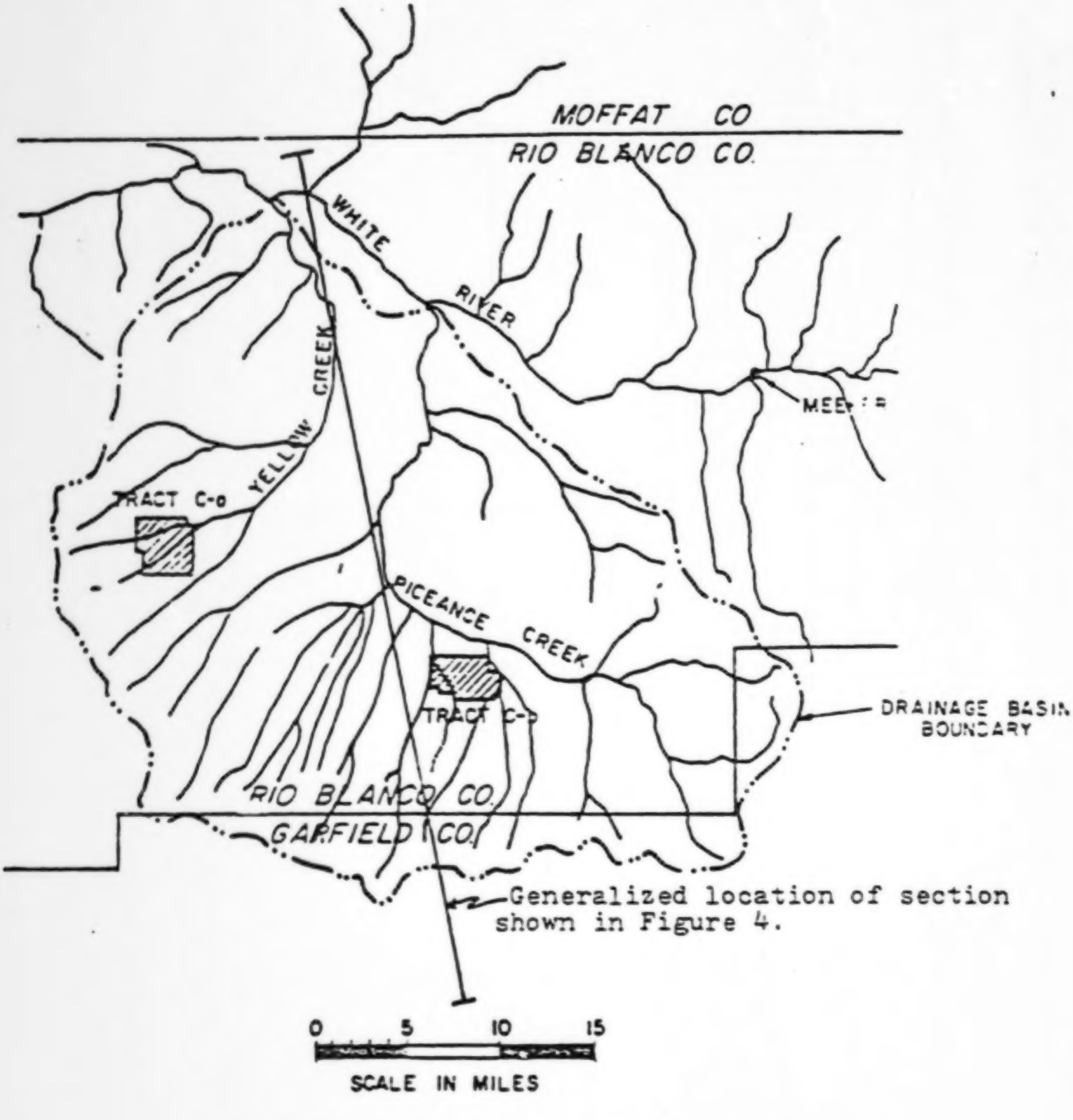
Figure 2

121


Mouth Yellow Creek
Secs. 9, 10 and 15, T. 2 N., R. 98 W.
U.S.B.M.-AEC
Yellow Creek Corehole 1
Sec. 13, T. 1 S., R. 99 W.
Ohio Oil Company
Ryans Creek 1
Sec. 34, T. 1 S., R. 98 W.
Shell Oil Company
Greeno 1
Sec. 4, T. 3 S., R. 97 W.
Thurman
Gov't 1
Sec. 16, T. 4 S., R. 97 W.
Getty Oil Company
Corehole 2
Sec. 30, T. 5 S., R. 97 W.
Parachute Creek
T. 6 S., R. 96 W.
W. H. Bradley, 1931
12
10
13
14
15
16
17
UINTA FORMATION
(FORMERLY EVACUATION CREEK MEMBER OF GREEN RIVER FORMATION)
Freshwater lacustrine tuffaceous sandstone, siltstone, shale and oil shale
Saline lacustrine oil shale
Tuffaceous sandstone
Evaporites and oil shale
Mahogany bed
A Groove
B Groove
Mud flats
PARACHUTE CREEK MEMBER OF GREEN RIVER FORMATION
Saline lacustrine oil shale
Evaporites, nahcolite, halite, etc., and oil shale
Saline lacustrine oil shale
Mud flat mudstone, sandstone, siltstone, and some oil shale
GARDEN GULCH MEMBER OF GREEN RIVER FORMATION
Orange marker
Saline lacustrine oil shale
Saline lacustrine oil shale
Freshwater lacustrine low grade oil shale
Unnamed tongue of Wasatch Formation
Swamp carbonaceous shales
DOUGLAS CREEK MEMBER OF GREEN RIVER FORMATION
Freshwater pond limestone and nonred bed fluvial shale and sandstone
Nonred bed fluviatile mudstone and sandstone
MAIN BODY OF WASATCH FORMATION
Red bed fluviatile mudstone and sandstone
Type section of Parachute Creek Member (Bradley, 1931)
Type section of Garden Gulch Member (Bradley, 1931)
200
150
100
50
0
METERS
KILOMETERS 10
5
0

Sedimentologic and stratigraphic cross section showing depositional environments and rock types from north to south across the Piceance Basin. Location of section is shown in Figure 3. From Koehler in Murray, 1974, p. 61.

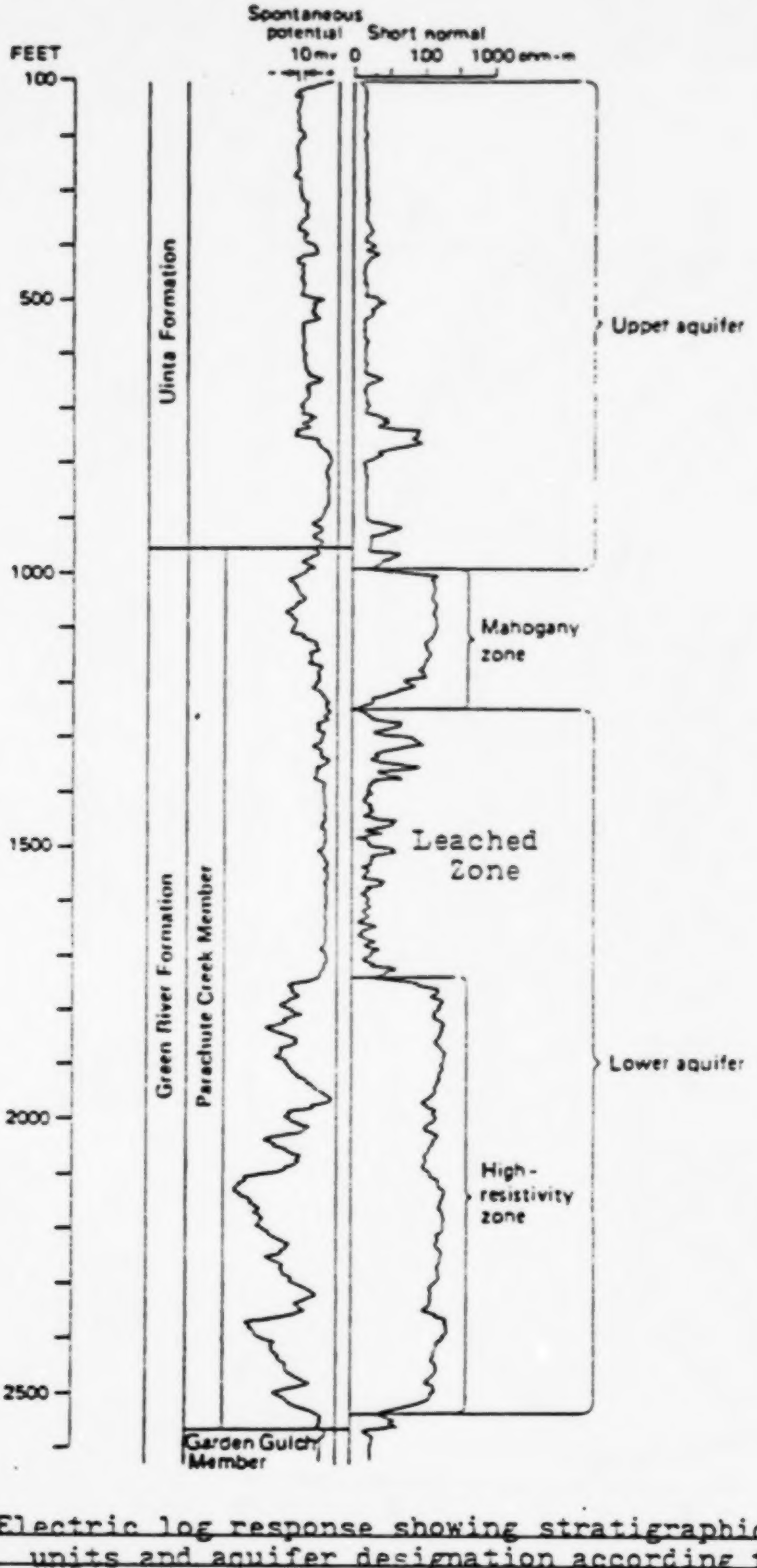
Figure 4



Generalized location of section shown in Figure 4.

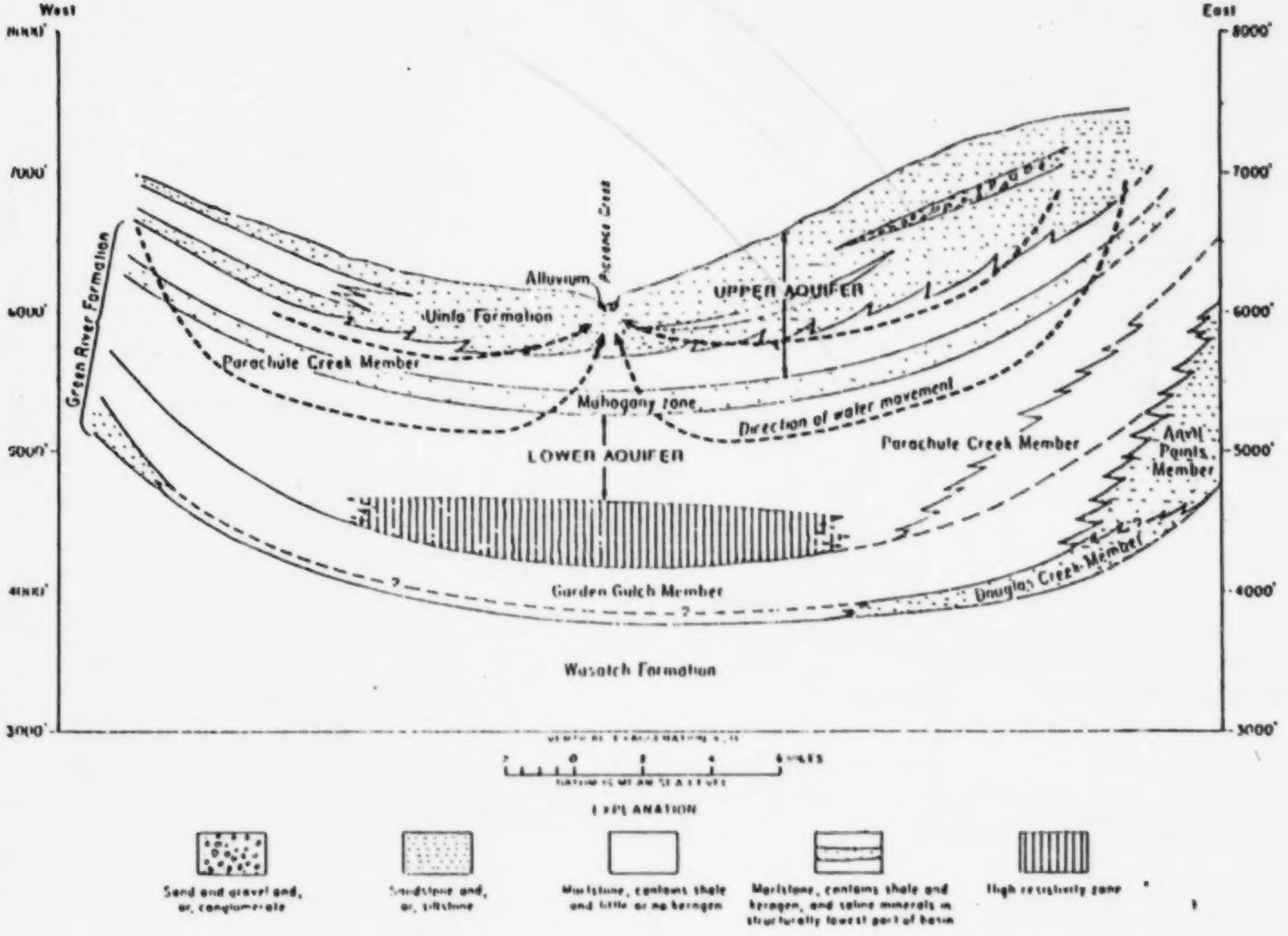
Map showing locations of Tracts Ca and Cb in the Piceance Creek basin, western Colorado. From Cb Detailed Development Plan Report.

Figure 3



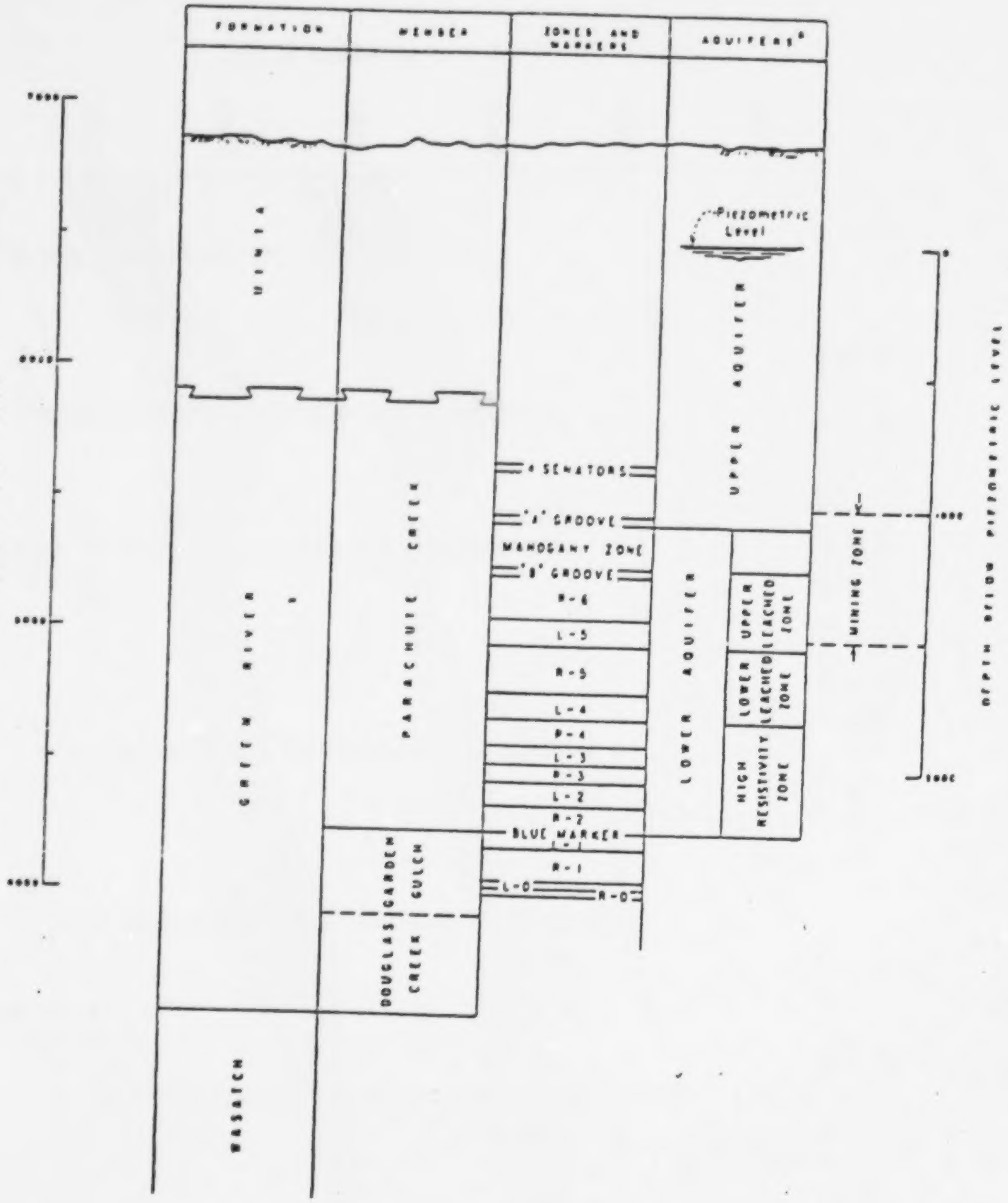
Electric log response showing stratigraphic units and aquifer designation according to the USGS in the Piceance Basin (From Welder and Saulnier, 1978, p.4)

Figure 6



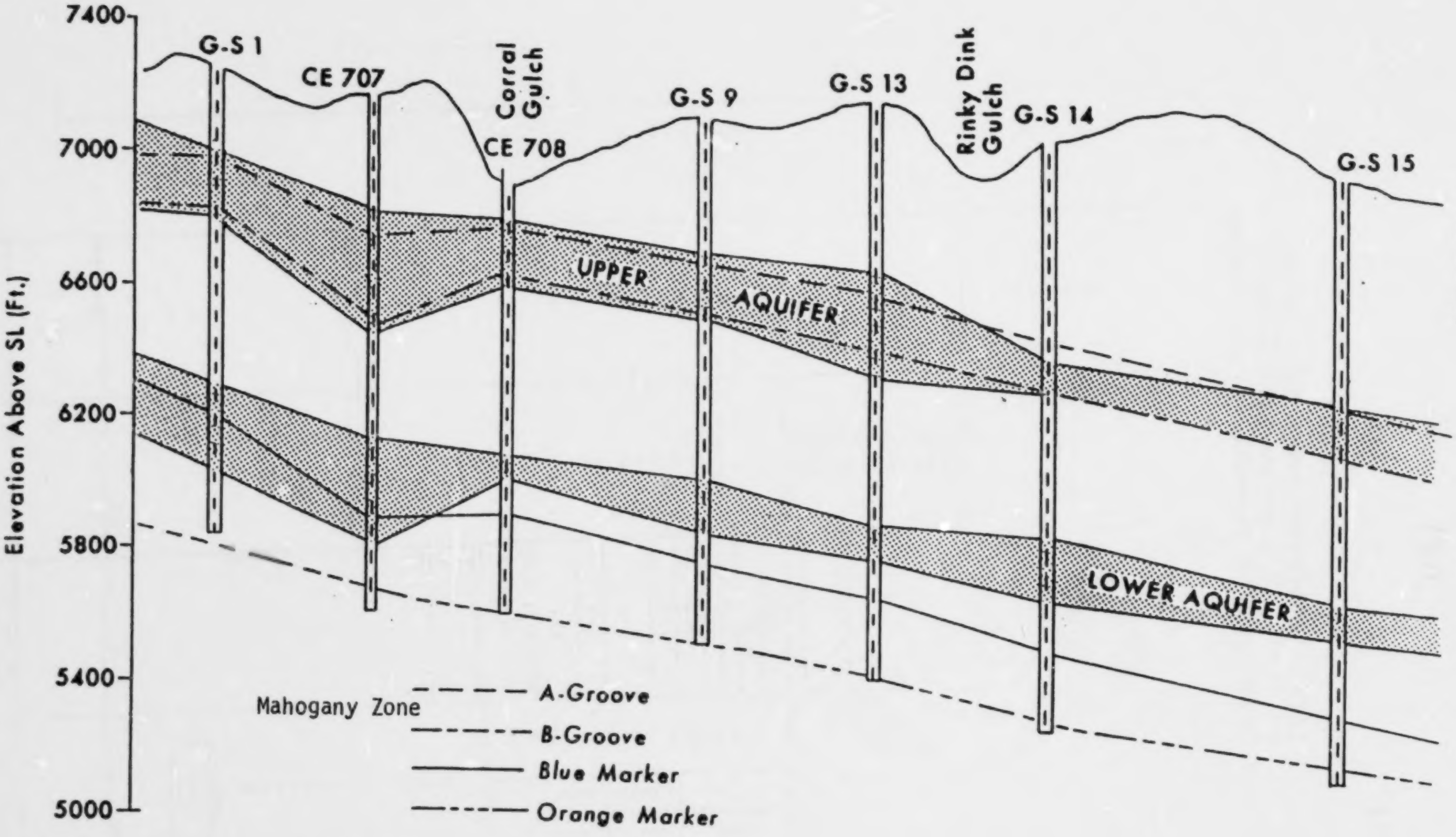
Schematic cross section showing upper and lower aquifers, interpretations of ground-water movement, and stratigraphic units in the Piceance Basin according to the U.S. Geological Survey(from Weeks, 1974, p. 177).

Figure 5



Relationships between stratigraphy and aquifer designations at tract Cb (From Tipton and Kalmbach, 1977)

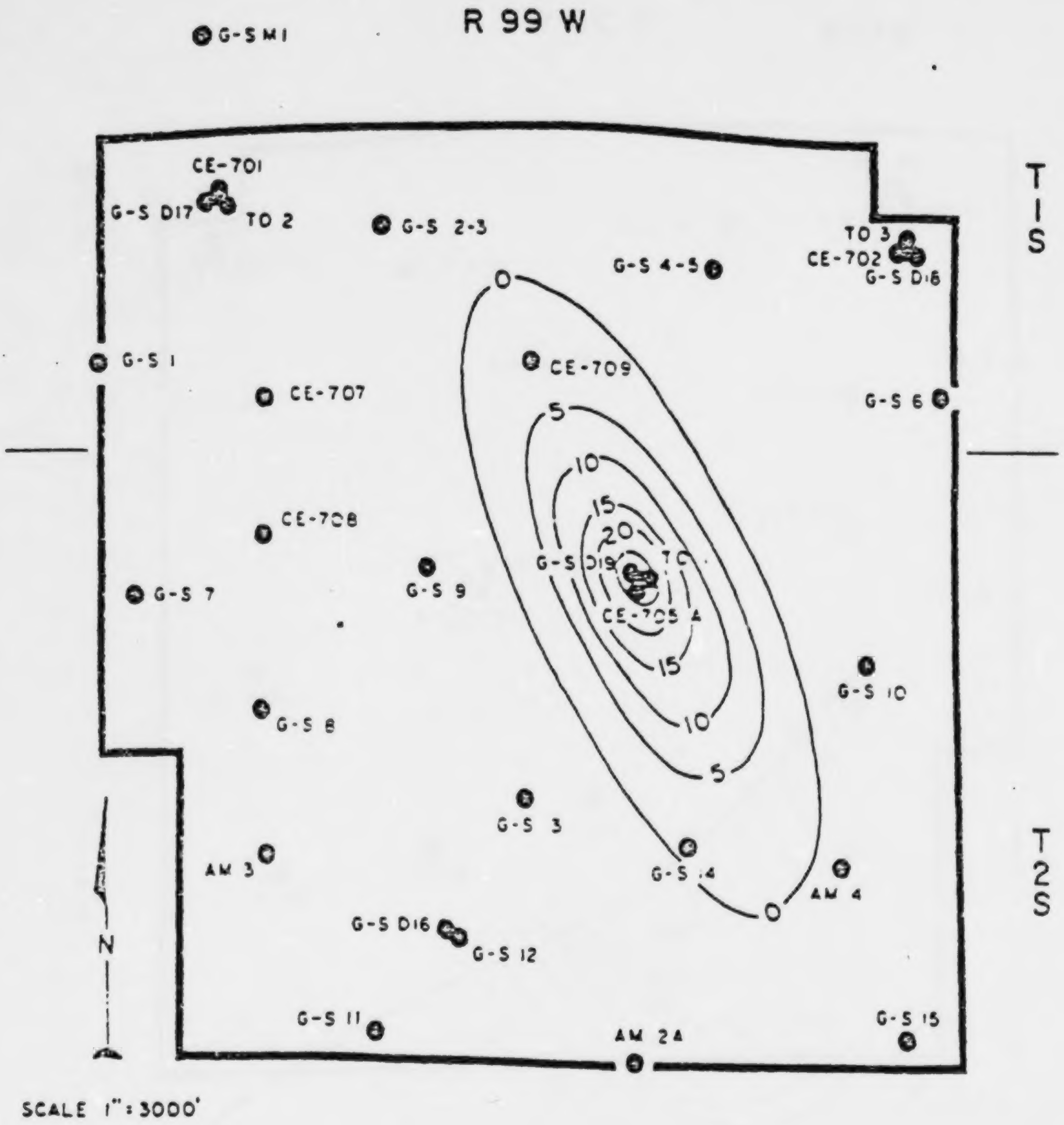
Figure 7



Base of Lower Aquifer Source:
RBOSC Final Environmental Baseline Report
for Tract C-a and Vicinity, 1977

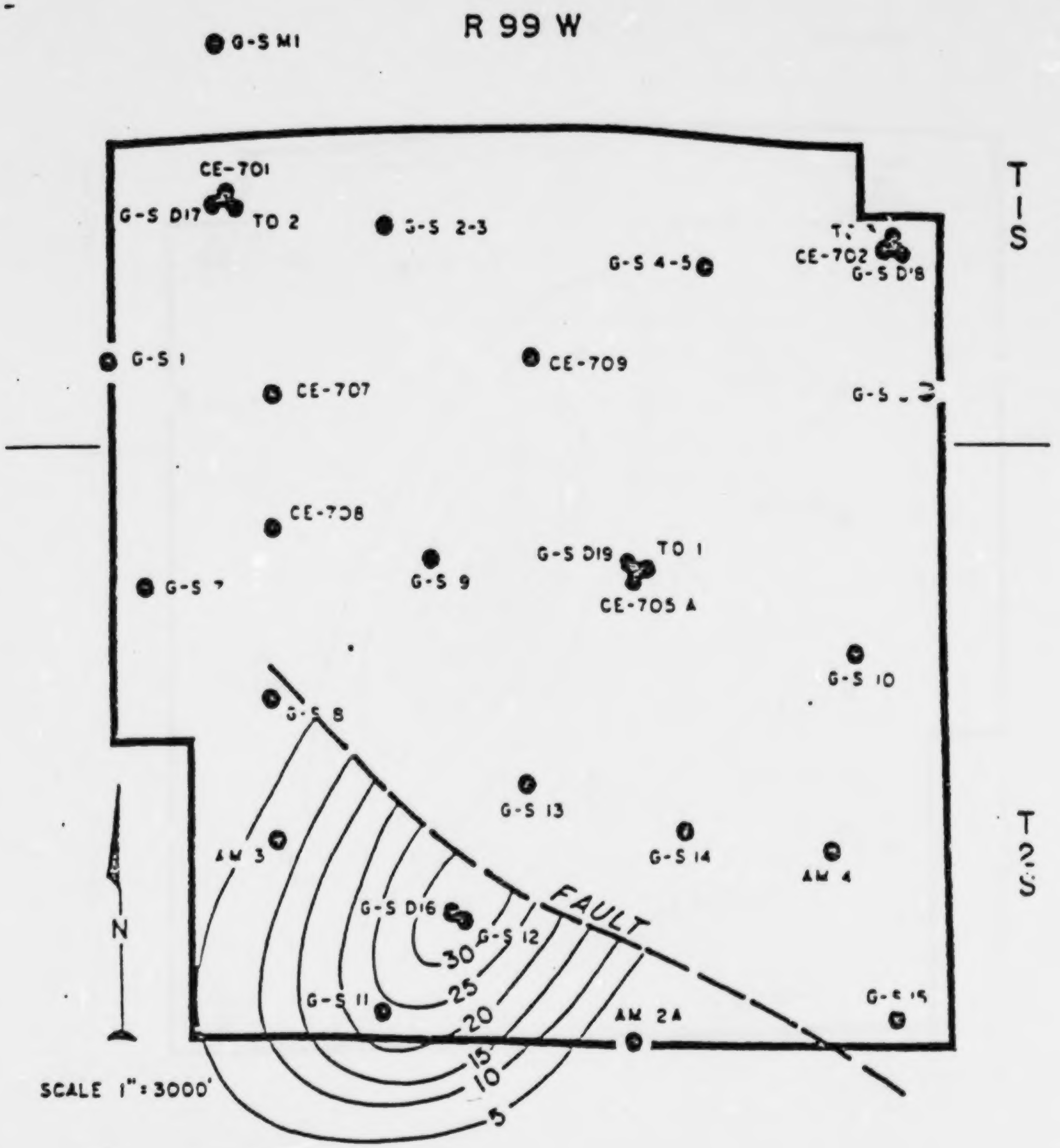
Figure 8

Northwest - southeast cross section through tract Ca showing relationships between aquifer designations and stratigraphy. Compare to Figure 7; refer to Figure 9 for hole locations. (R.B.O.S.C., 1977)



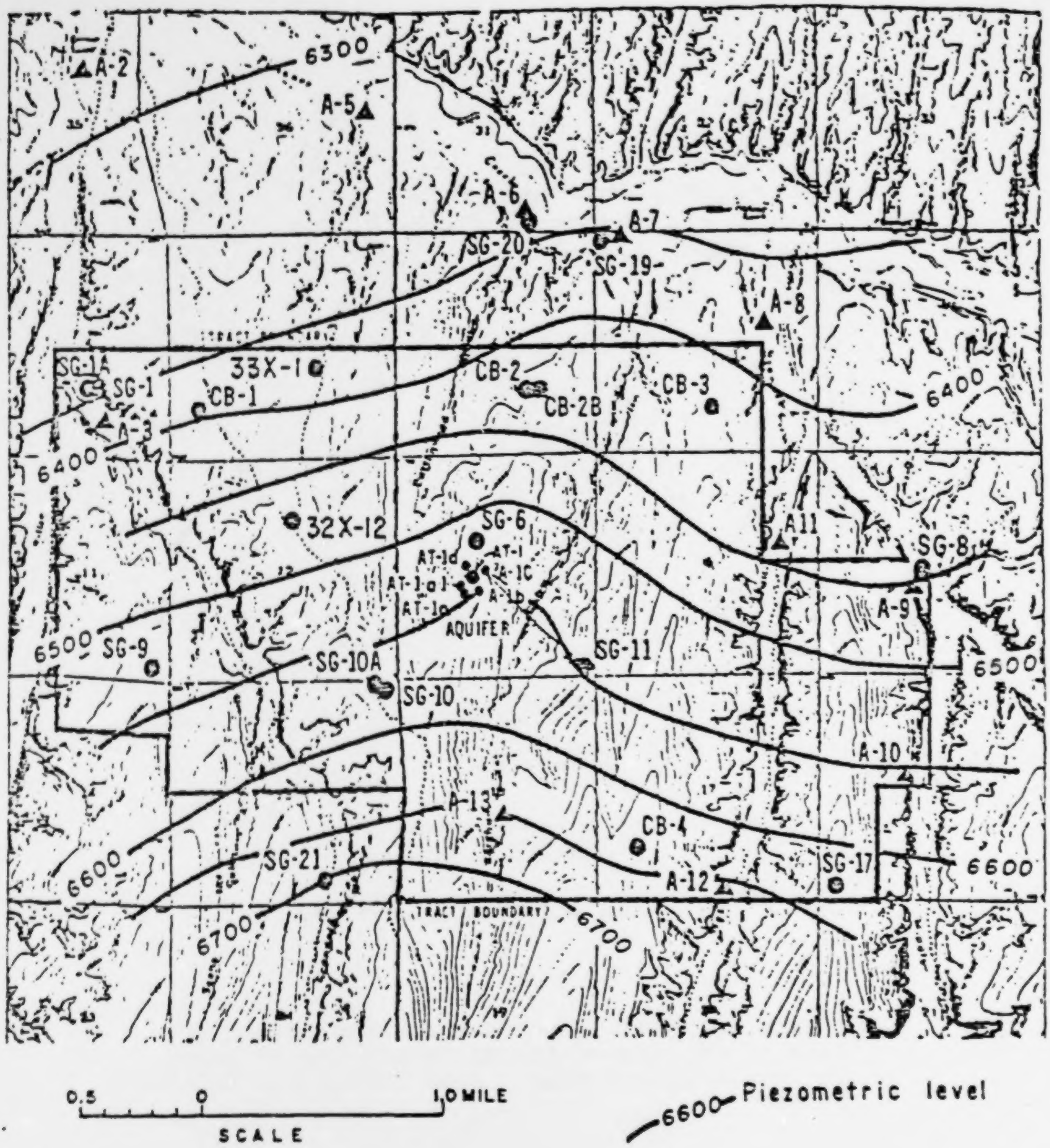
Map showing well locations at tract Ca, and anisotropy of drawdown, contours in feet, for pumping test in upper aquifer. (From Rio Blanco Oil Shale Project, 1977)

Figure 9



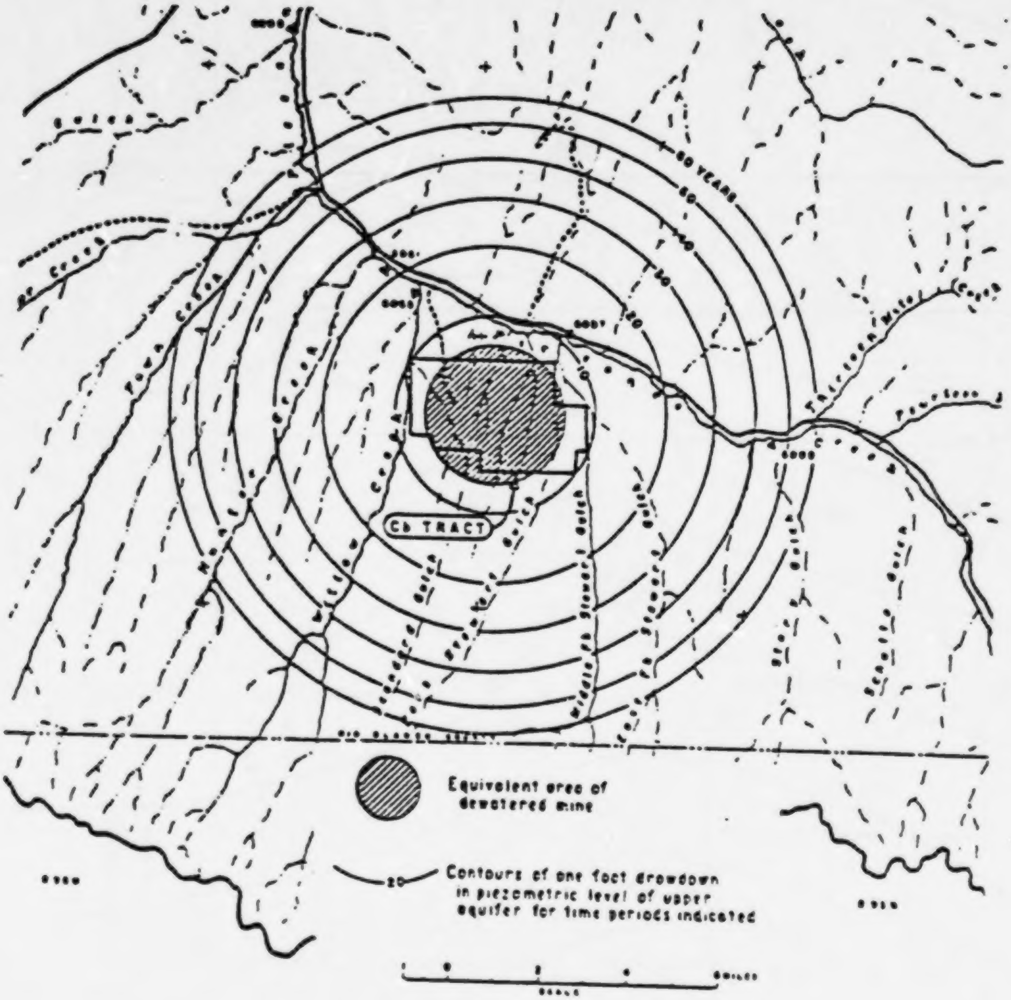
Map showing effect of fault boundary condition on drawdown, contours in feet, during pumping test of lower aquifer, tract Ca. (From Rio Blanco Oil Shale Project, 1977)

Figure 10



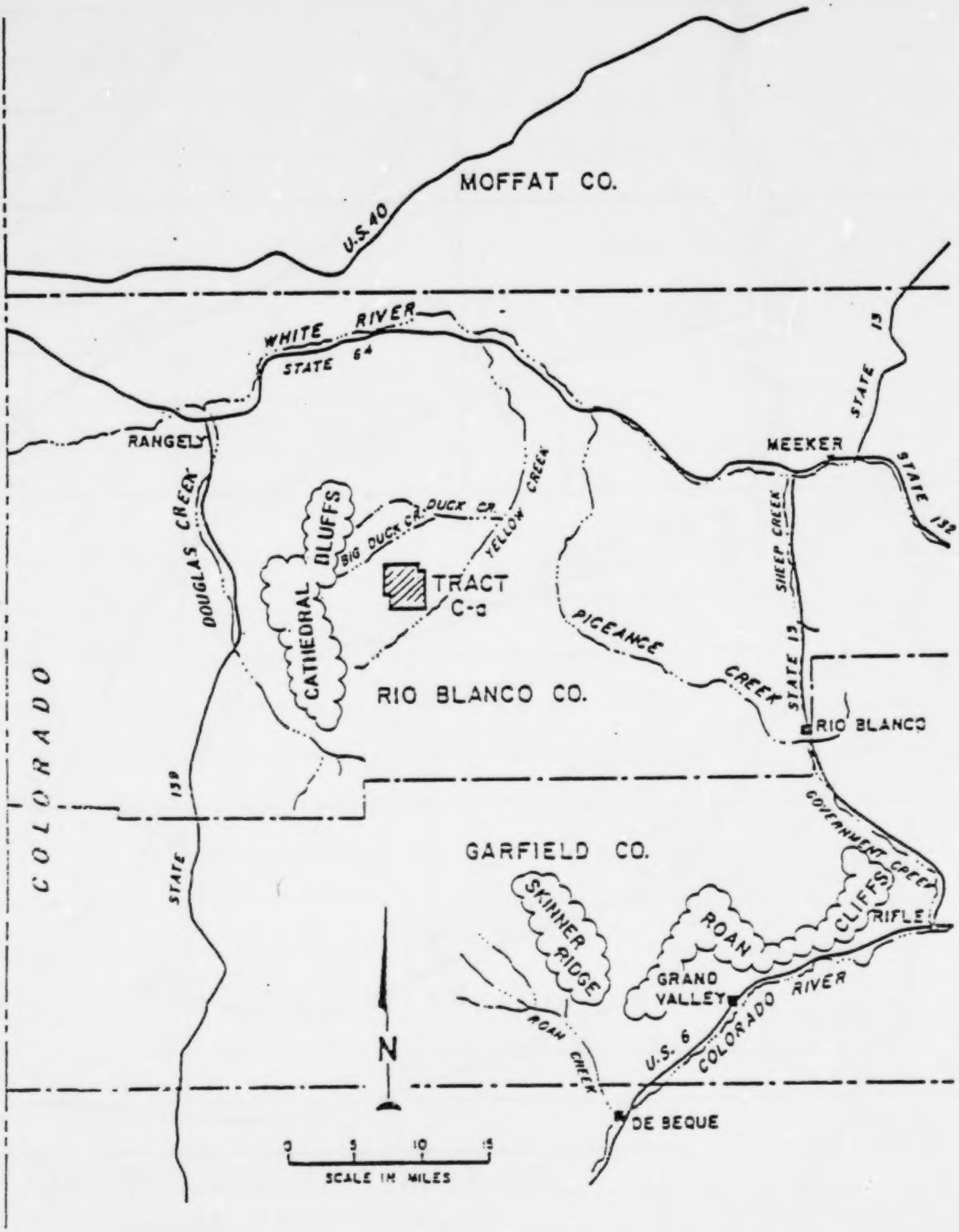
Map showing well locations and slope of the piezometric surface for the upper aquifer at tract Cb (From Tipton and Kalmbach, 1977)

Figure 11


60 YEARS
50
40
30
20
Cb TRACT
Equivalent area of dewatered mine
20
Contours of one foot drawdown in piezometric level of upper aquifer for time periods indicated

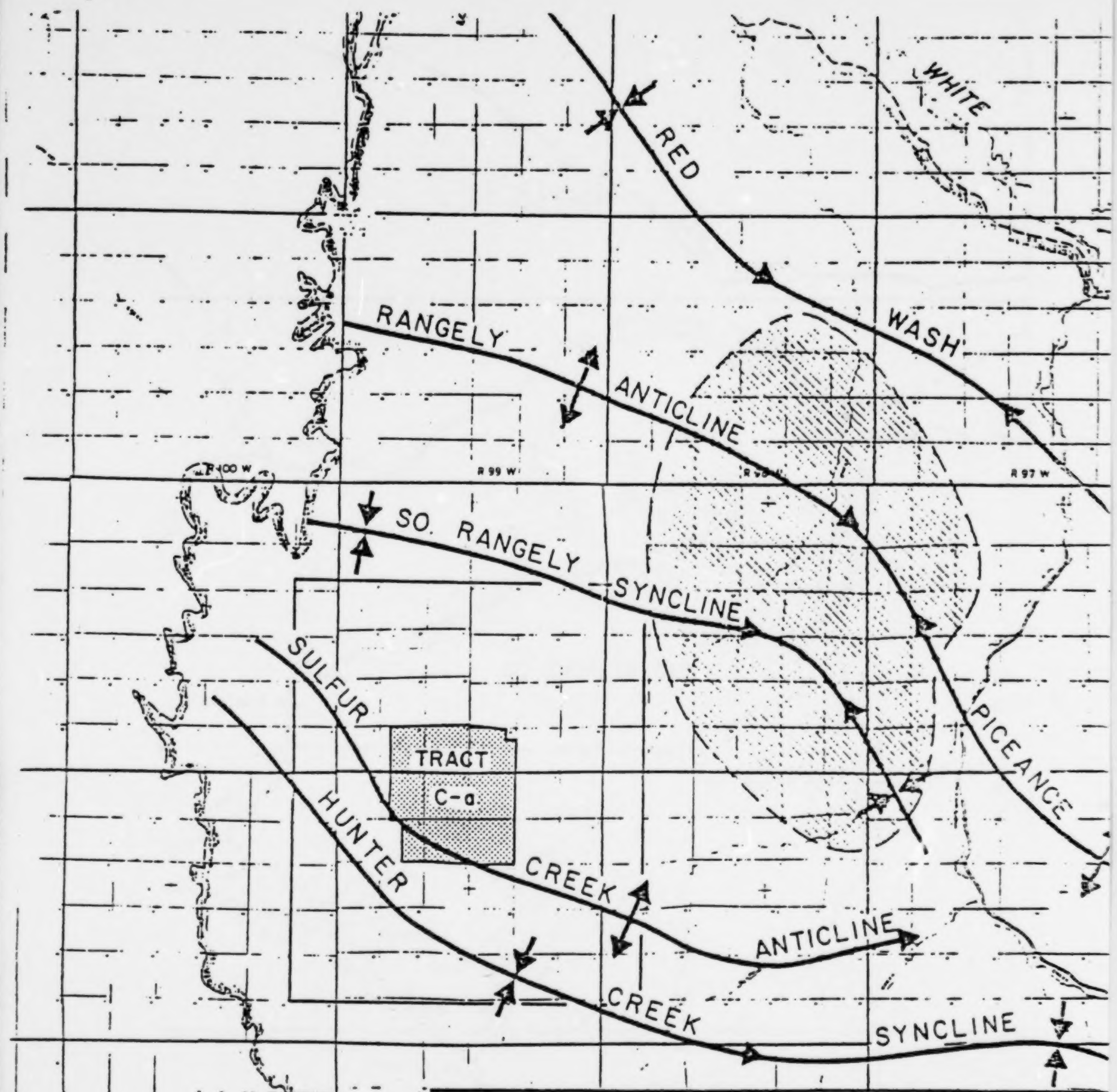
Map showing predictions of shape and extent of cone of depression due to dewatering of tract Cb for in-situ mining. From Tipton and Kalmbach, 1977.

Figure 12



RBOS Report 9, 1976

Figure 13



RIO BLANCO OIL SHALE PROJECT
RIO BLANCO COUNTY, COLORADO

REGIONAL GEOLOGIC MAP
OF THE PICEANCE CREEK BASIN
(BETWEEN THE WHITE AND COLORADO RIVERS)
NW COLORADO RBOS Sept. 1977

DRAWN BY	SCALE 1"-16,000'	Figure 14
DESIGN BY	DATE	

LEGEND

MAHOGANY LEDGE OUTCROP
(ZONE IN SUBSURFACE)

MAJOR FOLDS

ANTICLINAL AXIS

SYNCLINAL AXIS

↖ DIRECTION OF AXIS' PLUNGE

▨ SALINE DEPOCENTER OF
GREEN RIVER FORMATION
(AREA OF HALITIC ROCKS)

DATA SOURCES

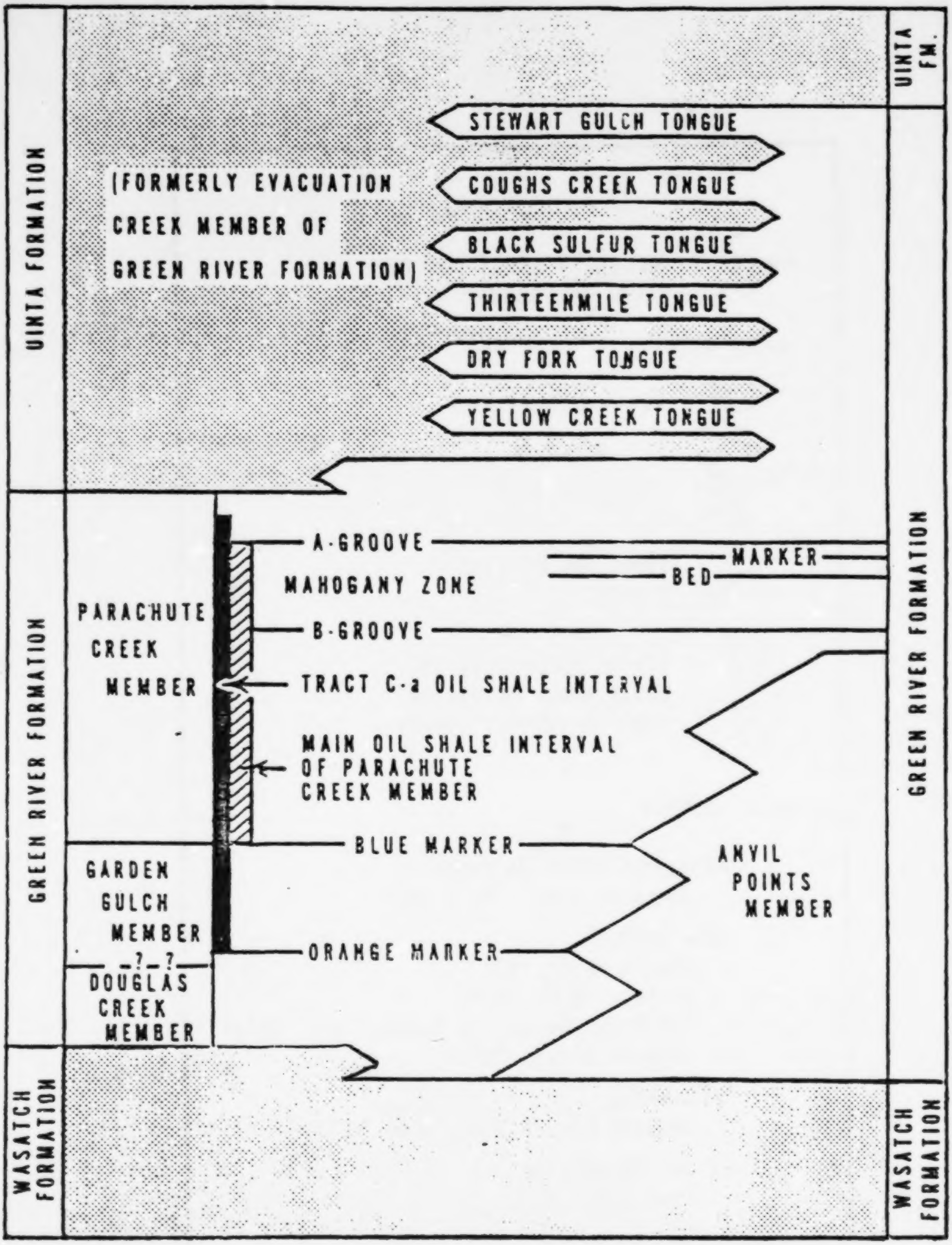
MAHOGANY LEDGE OUTCROP:
Cameron Engrs., Inc., 1977

FOLD TRENDS:
Austin, A.C., 1971
Mullens, M.C., 1976
Trollinger Geological Assoc., Inc., 1974
Amuedo & Ivy, 1975

FOLD NAMES:
Murray, D.K., & Haun, J.D., 1974

SALINE DEPOCENTER:
Dyni, J.R., 1974

Figure 15

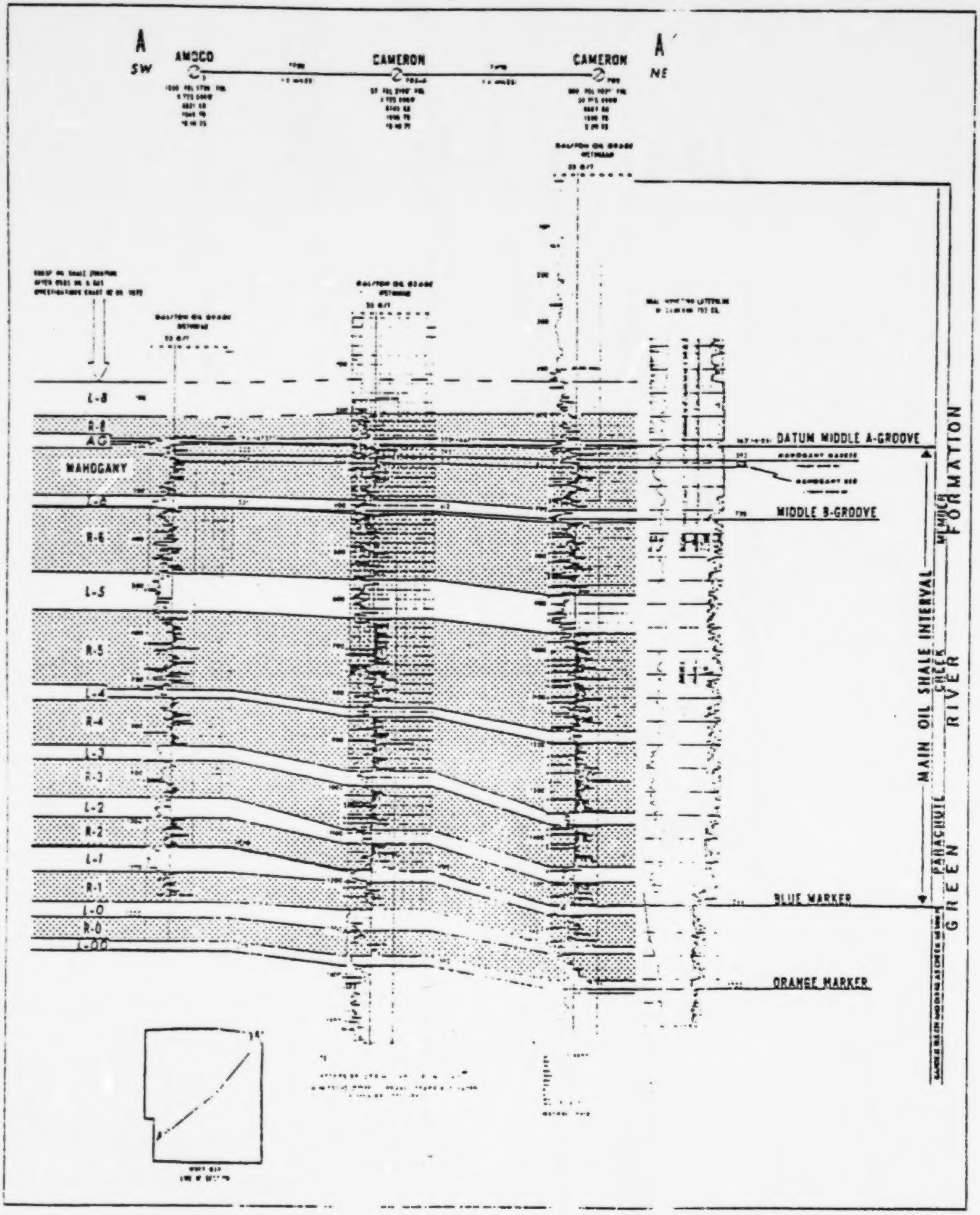


GENERALIZED STRATIGRAPHIC COLUMN OF TERTIARY EOCENE SERIES. PICEANCE CREEK BASIN

RBOS Sept. 1977

135

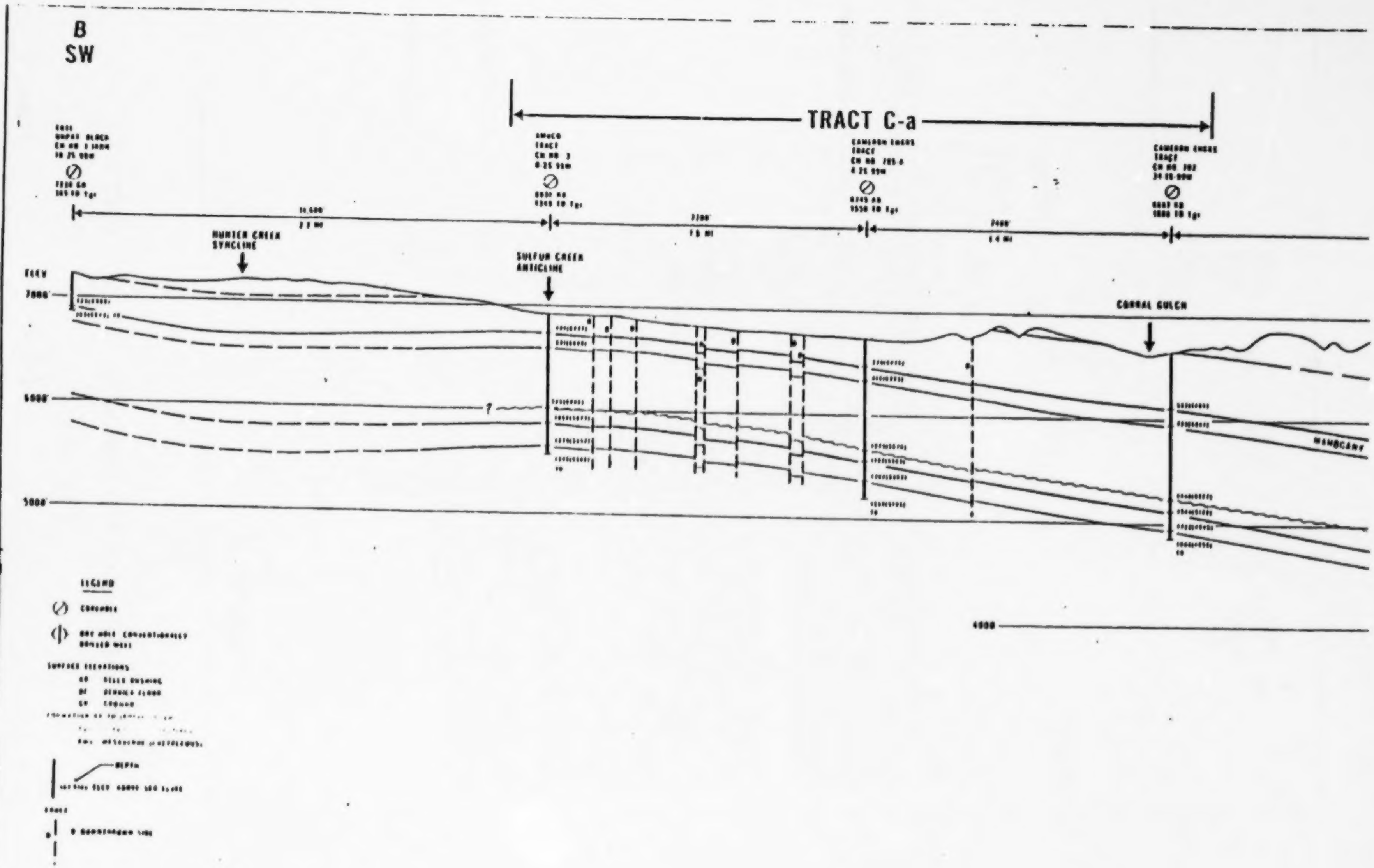
Figure 16



SW-NE 3-CORE HOLE HISTOGRAM CROSS SECTION. TRACT C-a

PBOS Sept. 1977

Figure 17



RBOS Sept. 1977 Figure 18

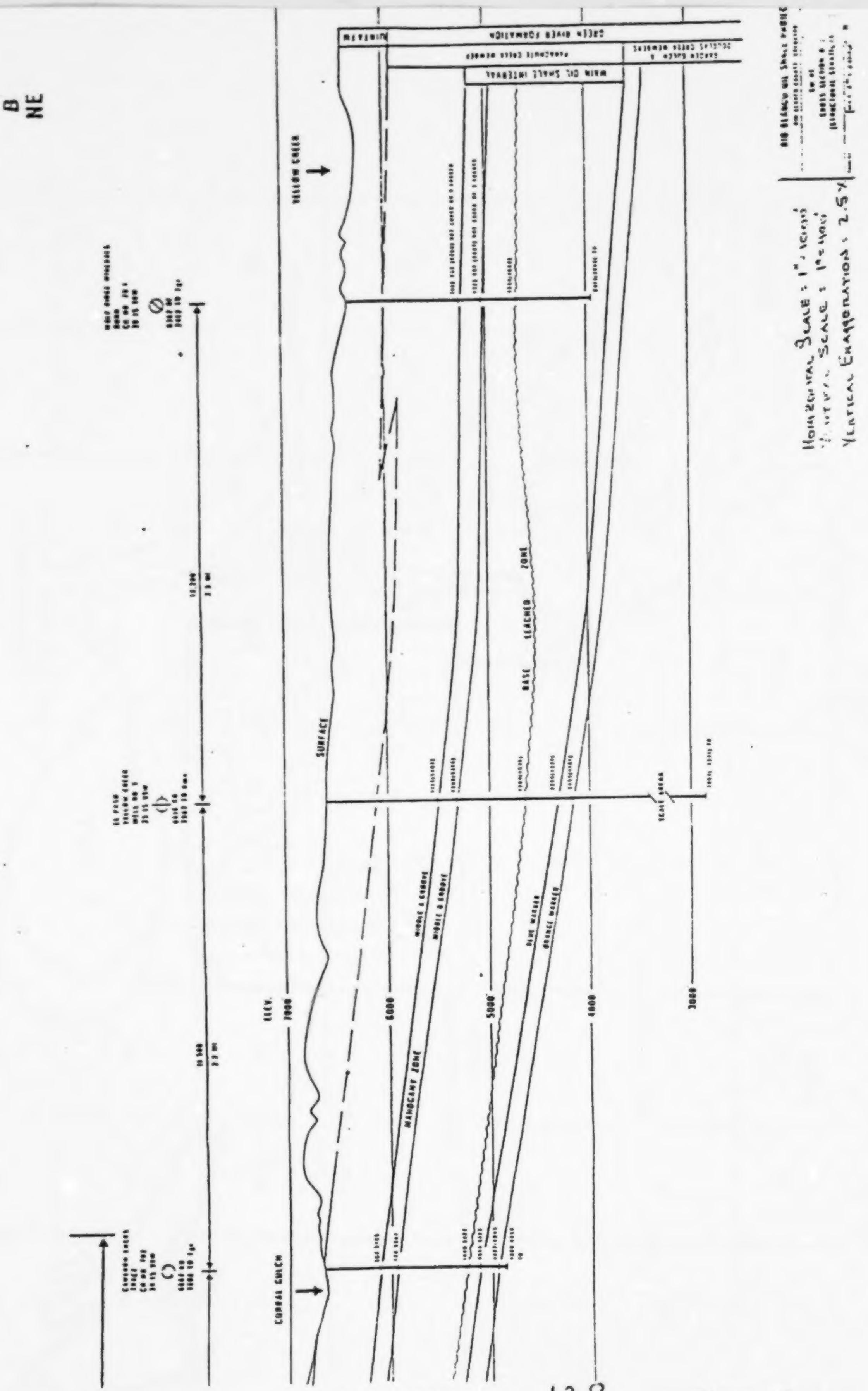
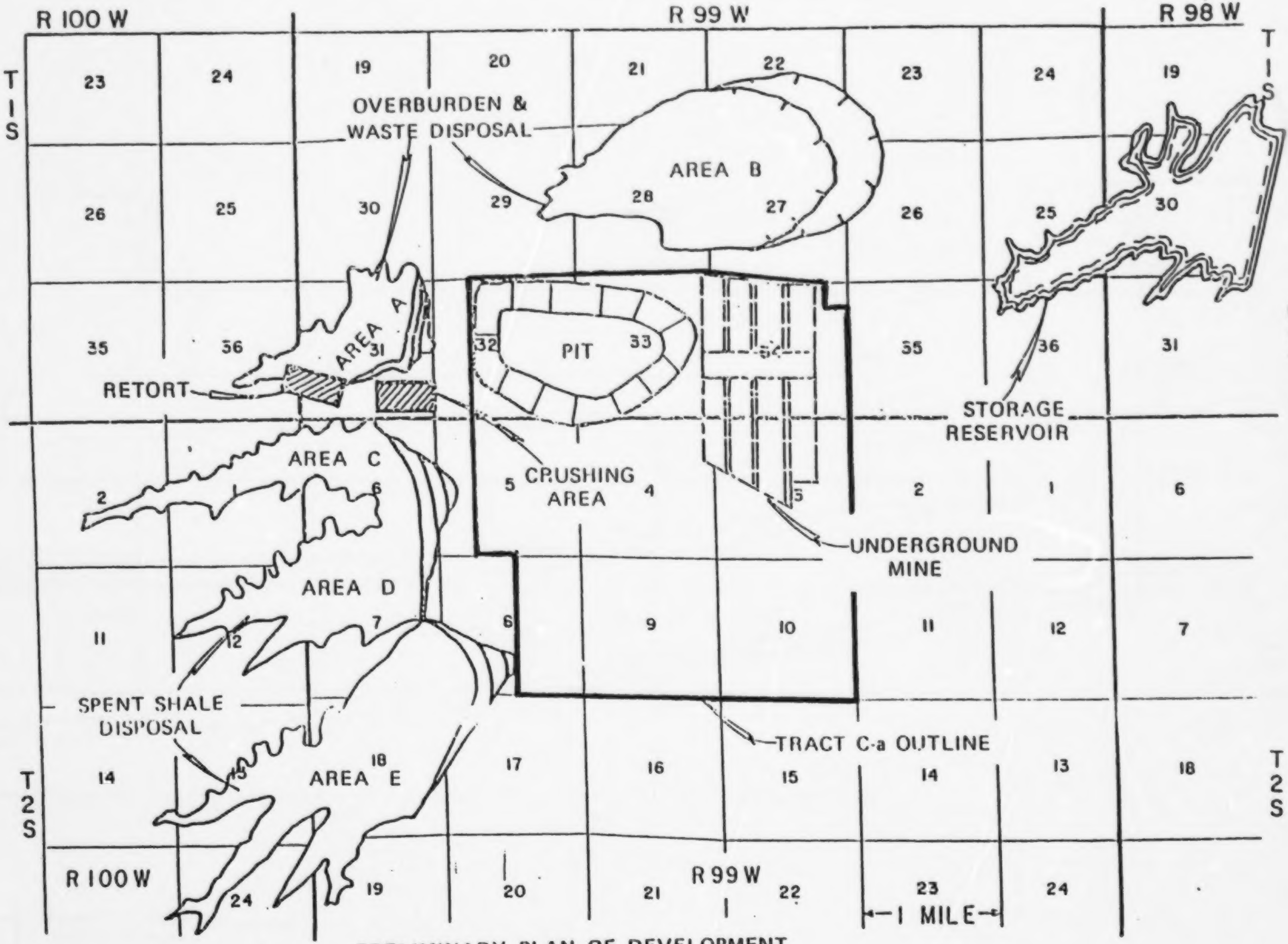

B
NE
YELLOW CREEK
CORRAL GULCH
SURFACE
ELEV.
7000
6000
5000
4000
3000
MAHOGANY ZONE
MIDDLE A GROOVE
MIDDLE B GROOVE
BLUE MARKER
ORANGE MARKER
BASE LEACHED ZONE
SCALE BREAK
GREEN RIVER FORMATION
UINTA
PARACHUTE CREEK MEMBER
MAIN OIL SHALE INTERVAL
GARDEN GULCH & DOUGLAS CREEK MEMBERS
HORIZONTAL SCALE : 1" = 1000'
VERTICAL SCALE : 1" = 400'
VERTICAL EXAGGERATION : 2.5X
RIO BLANCO OIL SHALE PROJECT
CROSS SECTION B
STRUCTURAL SECTION

Figure 18



PRELIMINARY PLAN OF DEVELOPMENT
TRACT C-a
PLAN OF OPEN PIT/UNDERGROUND COMBINATION MINING SCHEME

Figure 19

R.B.O.S.C., 1977

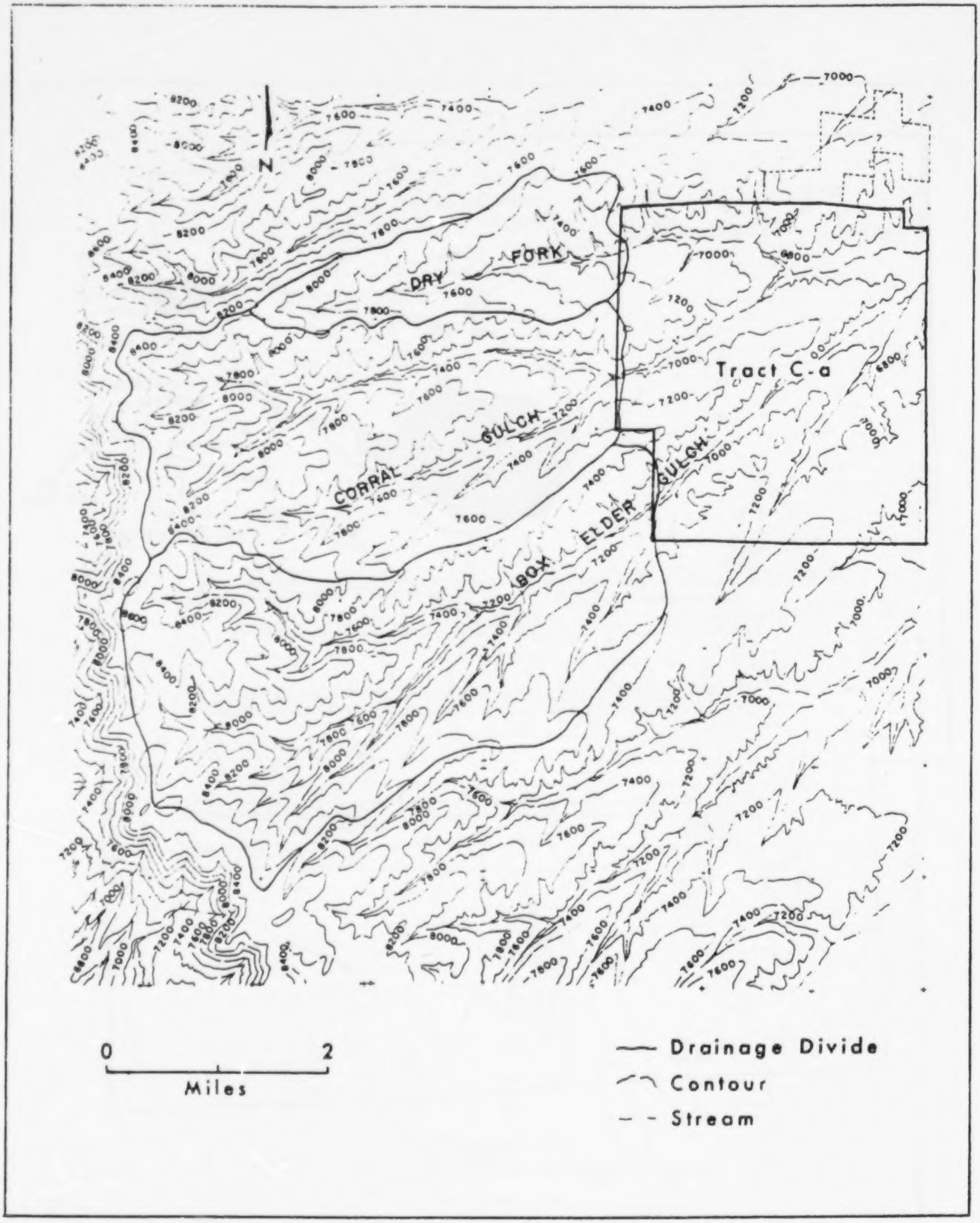


Figure 20
Tract C-a and Contributing Drainage Basins

R.B.O.S.C., 1981

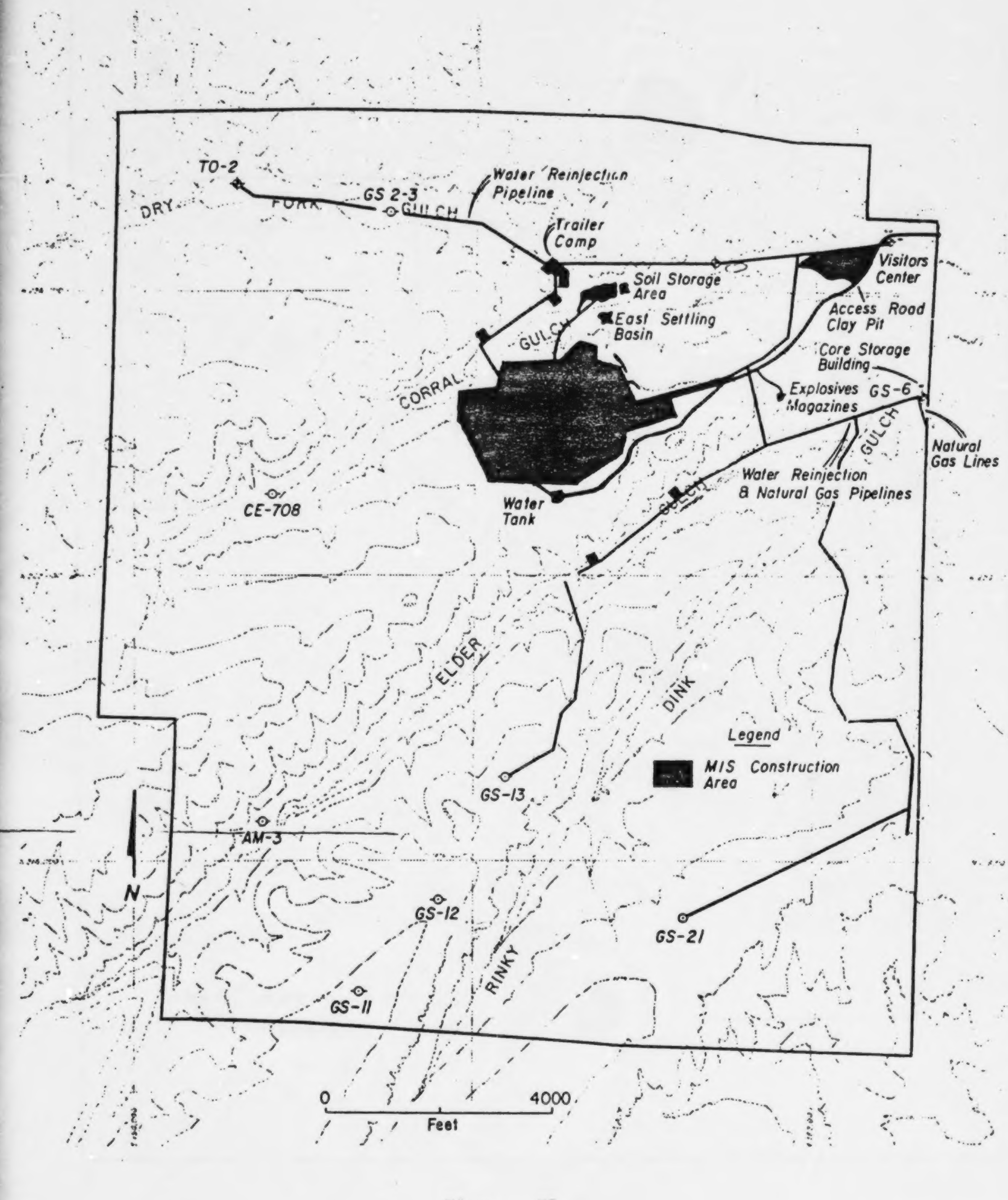
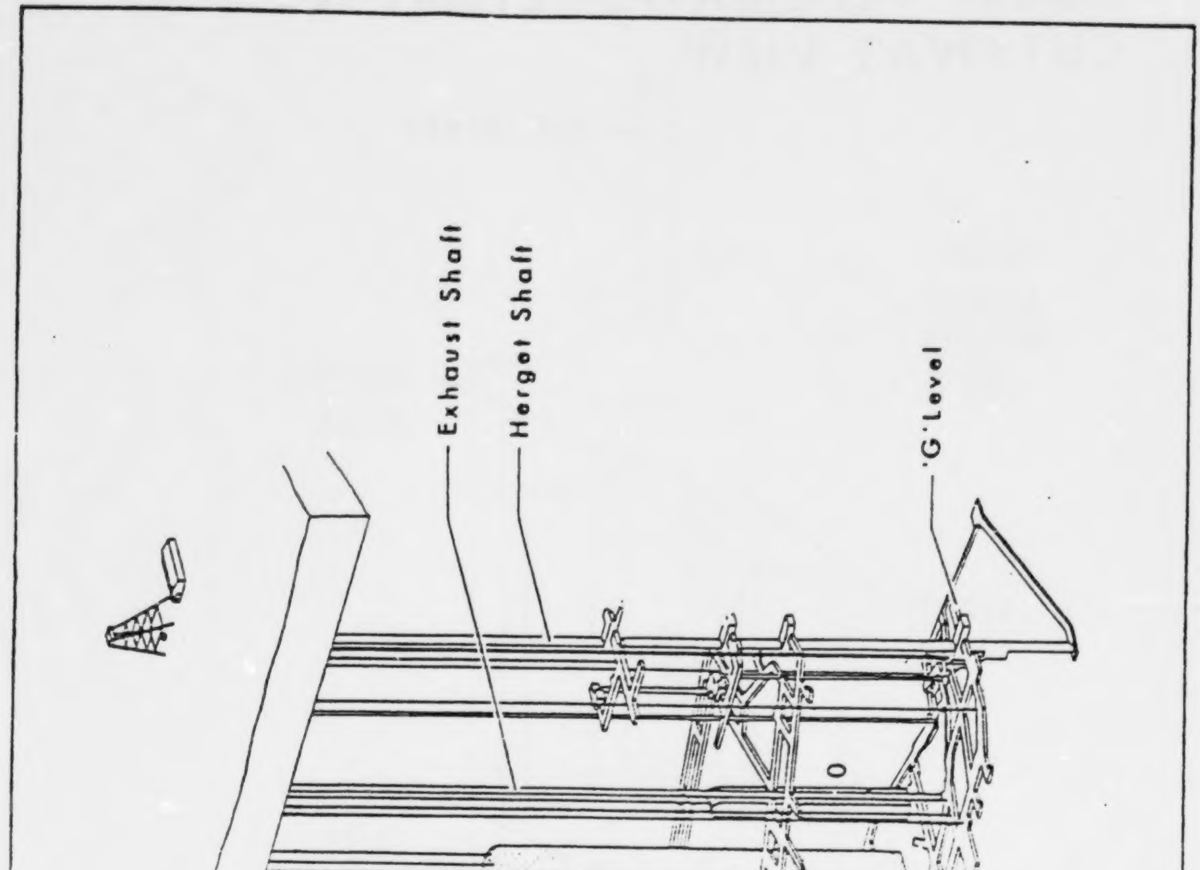


Figure 21
Tract C-a MIS Plot Plan

R.B.O.S.C., 1981

141

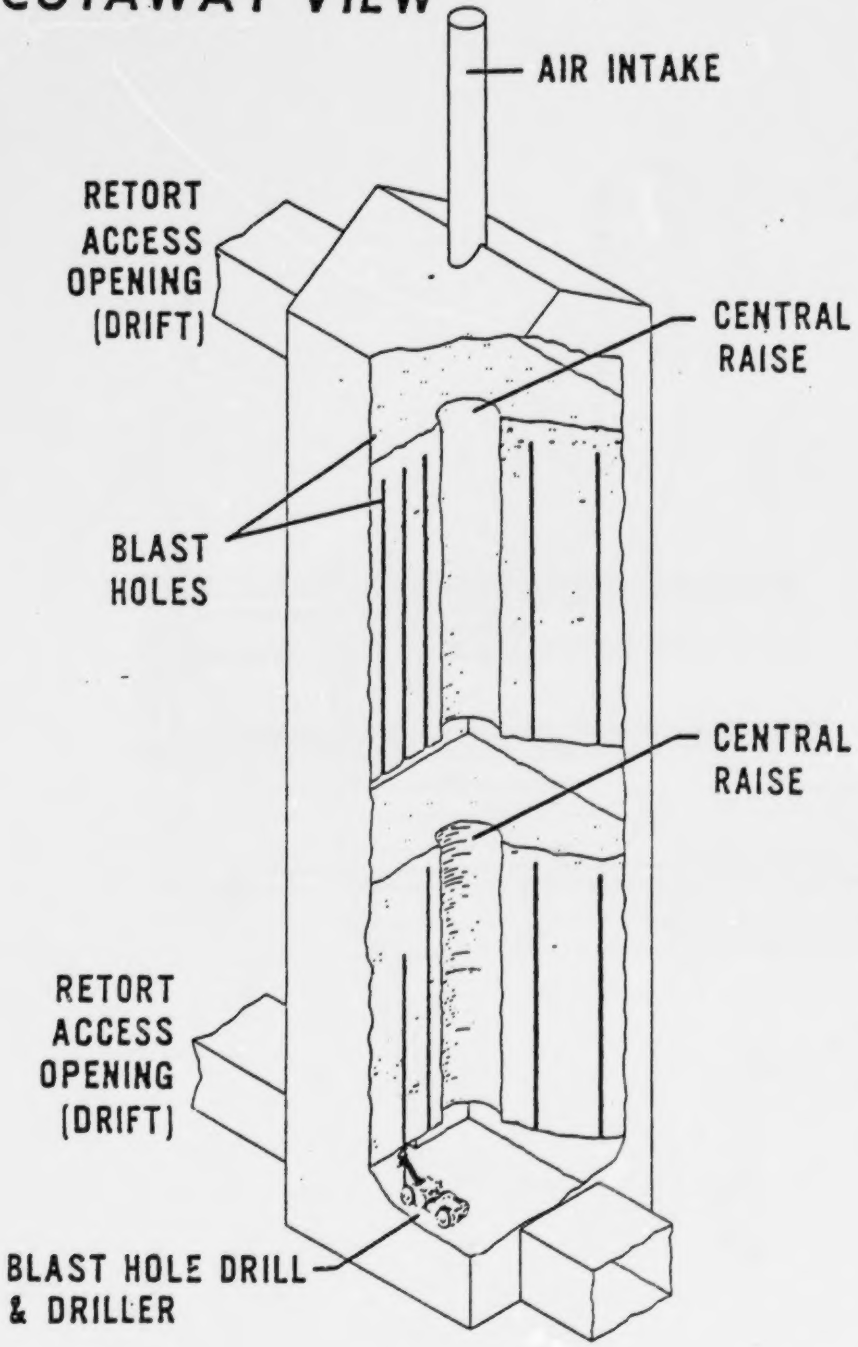


MDP Mine and Retort Development For MIS Retorts

RBOS Feb. 1981

Figure 22

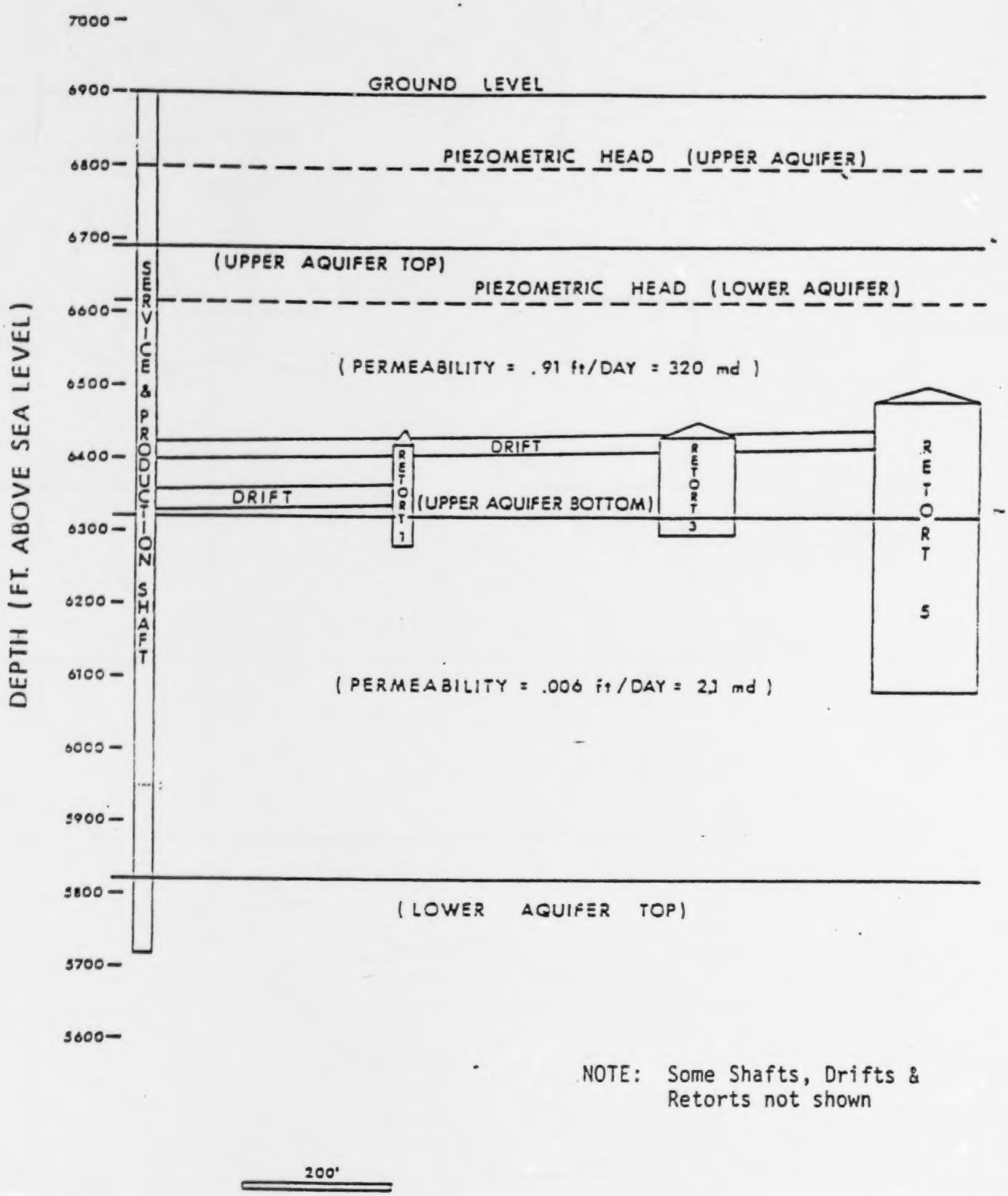
RBOSP SCHEMATIC RETORT NO. 1 CUTAWAY VIEW


AIR INTAKE
RETORT ACCESS OPENING (DRIFT)
CENTRAL RAISE
BLAST HOLES
CENTRAL RAISE
RETORT ACCESS OPENING (DRIFT)
BLAST HOLE DRILL & DRILLER

RBOSP SCHEMATIC RETORT NO. 1 CUTAWAY VIEW

RBOS Sept. 1977

Figure 23


7000
6900
6800
6700
6600
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
DEPTH (FT. ABOVE SEA LEVEL)
GROUND LEVEL
PIEZOMETRIC HEAD (UPPER AQUIFER)
(UPPER AQUIFER TOP)
PIEZOMETRIC HEAD (LOWER AQUIFER)
(PERMEABILITY = .91 ft/DAY = 320 md)
SERVICE & PRODUCTION SHAFT
DRIFT
DRIFT
RETORT 1
(UPPER AQUIFER BOTTOM)
RETORT 3
RETORT 5
(PERMEABILITY = .006 ft/DAY = 2.1 md)
(LOWER AQUIFER TOP)
200'

NOTE: Some Shafts, Drifts &
Retorts not shown

HYDROLOGICAL CROSS SECTION OF MINE AREA

RBOS Sept. 1977

Figure 24

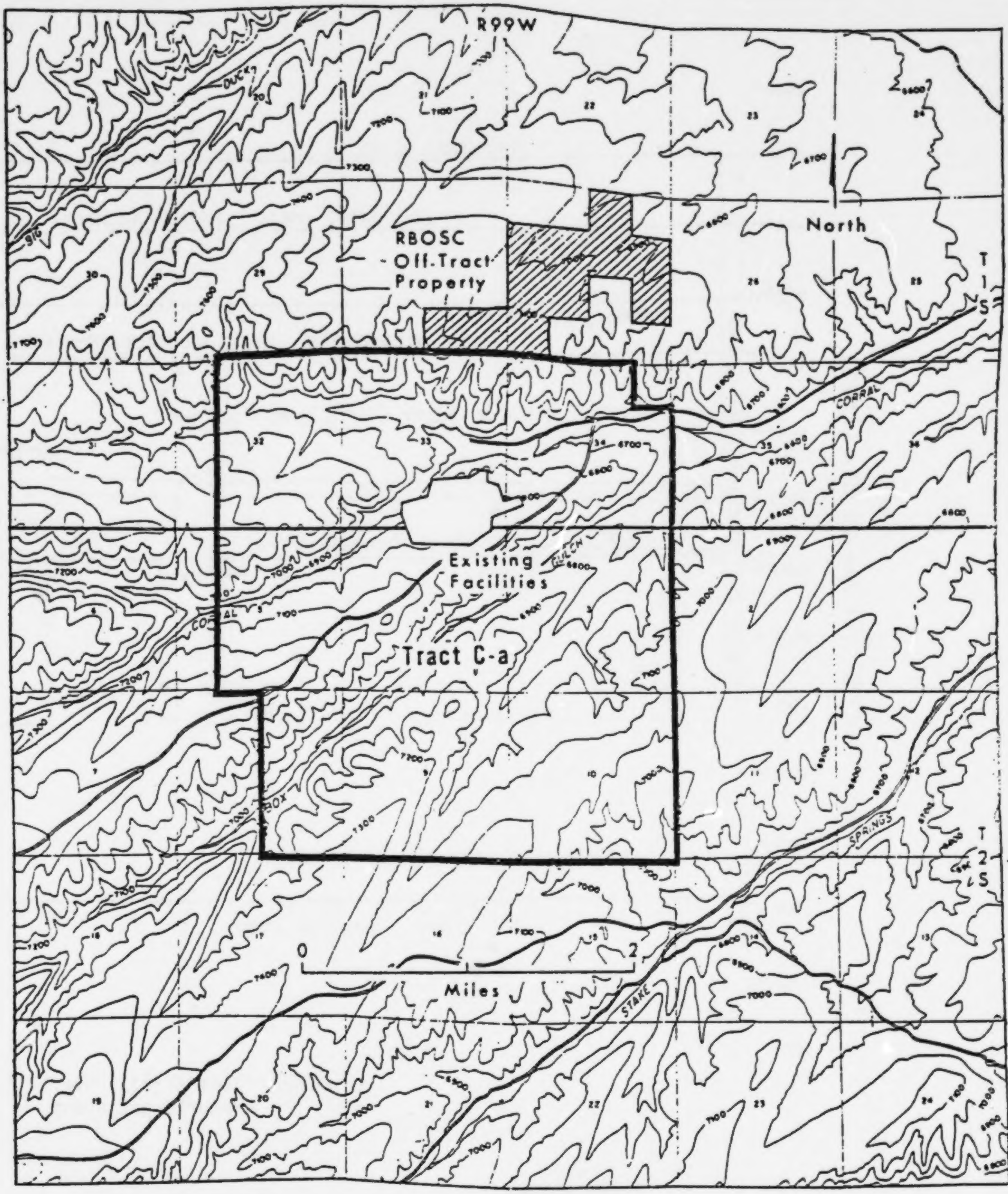


Figure 25

Lurgi Demonstration Project Off-Tract Site Location

RBOS Feb. 1981

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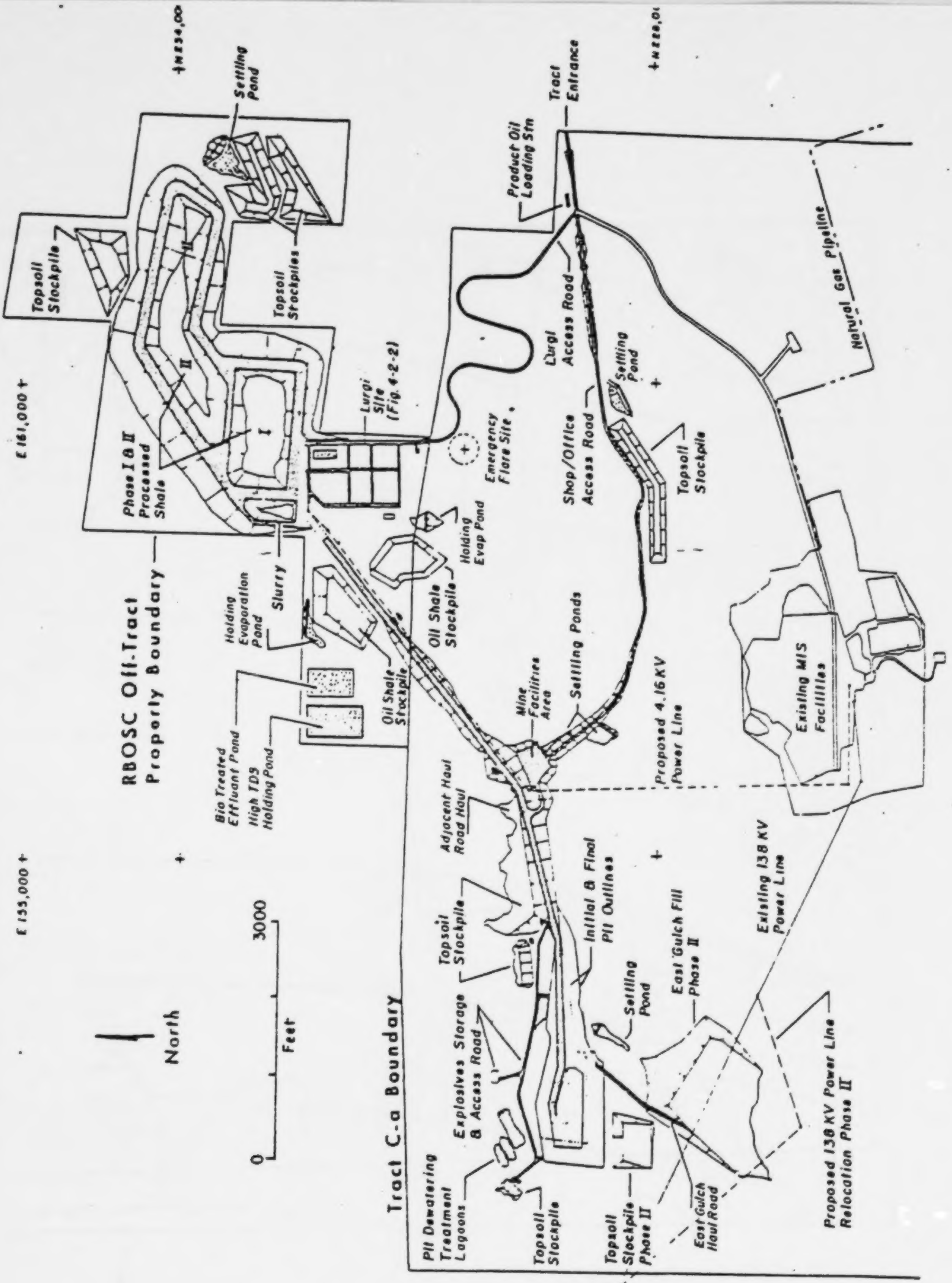
Figure 25



Lurgi Demonstration Project Plot Plan

RBOS Feb. 1981

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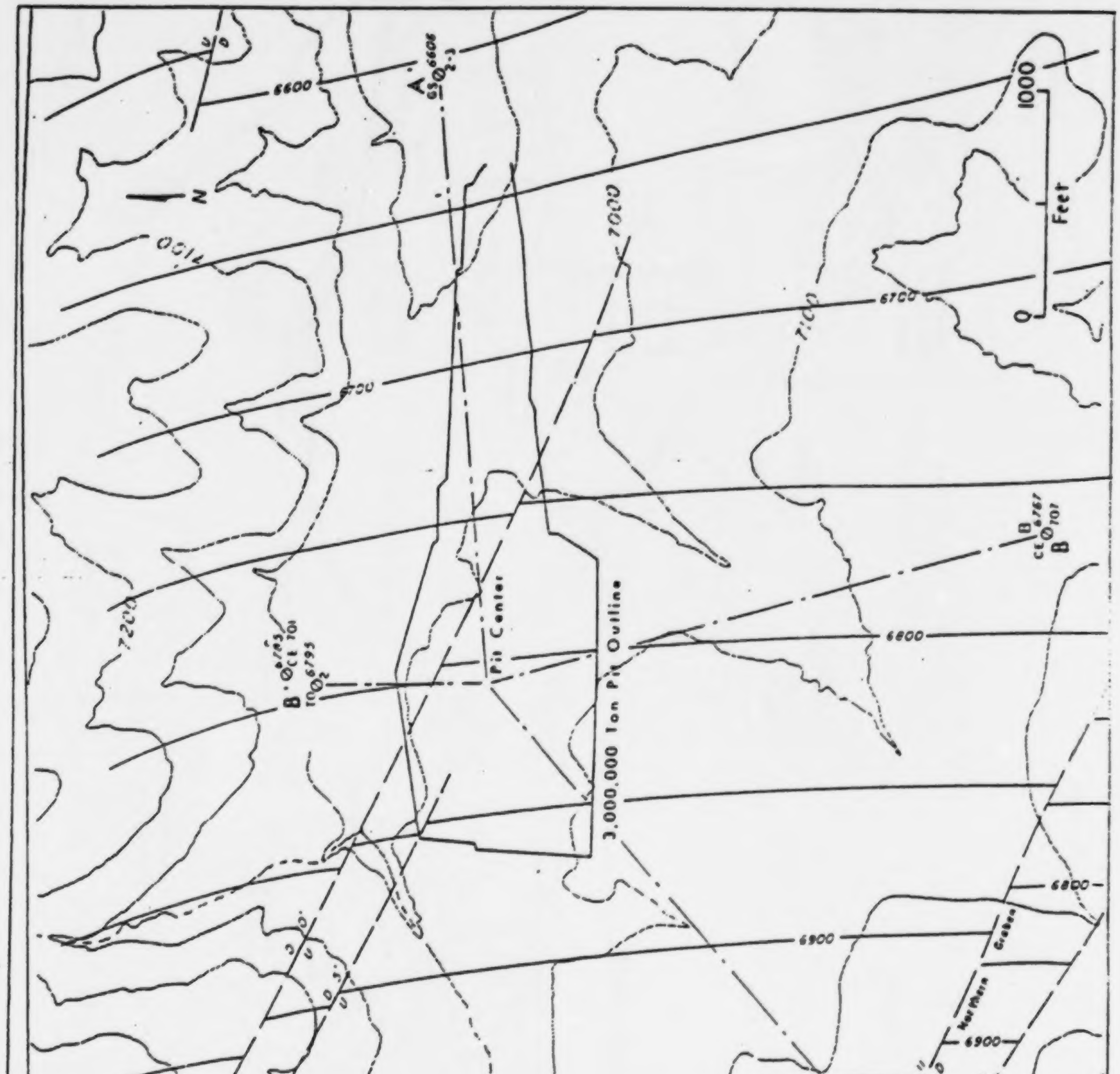
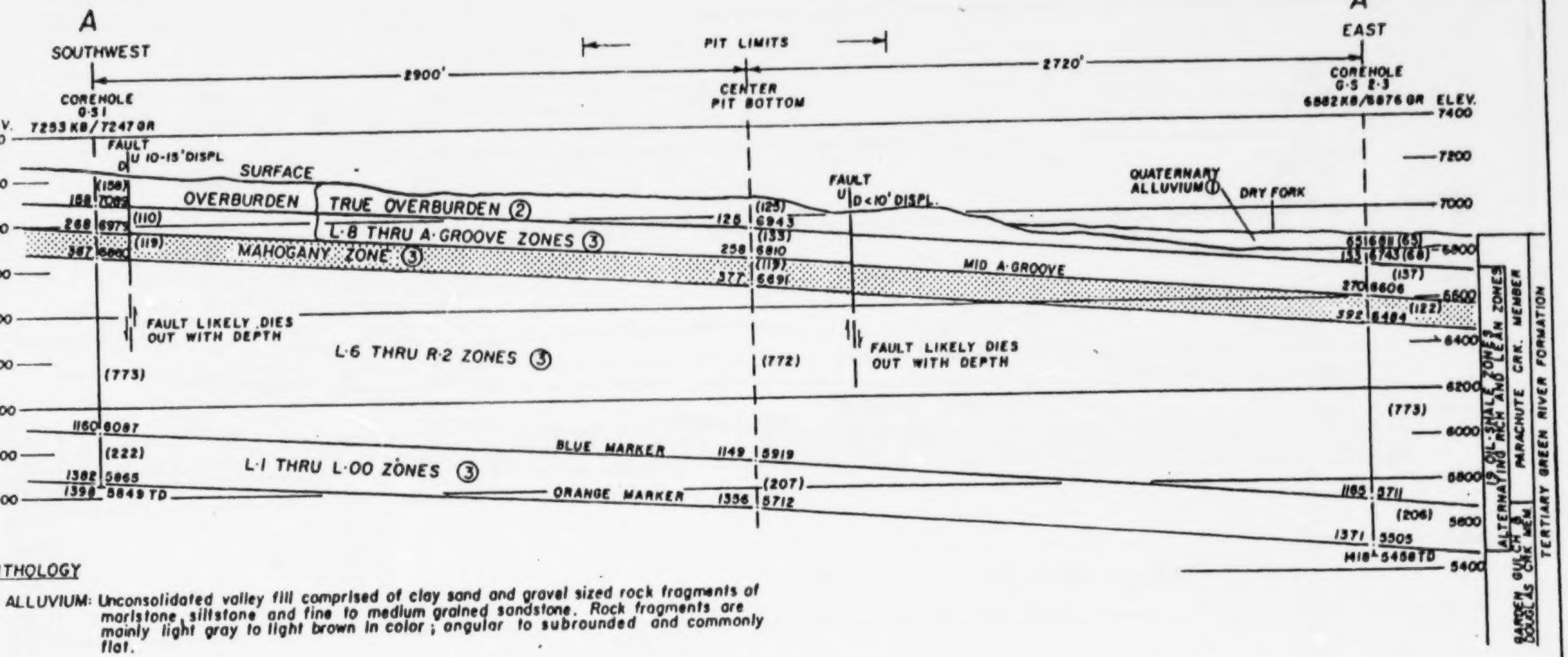
Figure 26



MIDDLE 'A'-GROOVE STRUCTURE

RBOS Feb, 1981



LITHOLOGY

① ALLUVIUM: Unconsolidated valley fill comprised of clay sand and gravel sized rock fragments of marlstone, siltstone and fine to medium grained sandstone. Rock fragments are mainly light gray to light brown in color; angular to subrounded and commonly flat.

② TRUE OVERBURDEN: Dominantly barren (non-kerogenaceous) light gray marlstone interbedded with lesser amounts of thin gray siltstone and fine-grained sandstone. Occasional thin beds of light to medium brown marlstone (kerogenaceous; oil shale) are scattered in the lower half of this interval.

③ L-8 THRU L-OO: 19 oil shale zones, alternating relatively rich and lean in grade. Dominantly light gray to dark brown and black marlstone (oil shale) containing varying amounts of kerogen. Numerous thin tuff beds (volcanic ash) interbedded with the oil shale. Nahcolite is scattered throughout many zones but only in minor amounts. Dawsonite is confined to zones R·2, thru R·5.

0 1000
Feet

LEGEND

DEPTH (FT.)	ELEVATION (FT.)
258	6810
	(119) INTERVAL THICKNESS (FT.)
377	6691

U D 10' FAULT; UP & DOWNTHROWN SIDES, DISPLACEMENT

KB = KELLY BUSHING ELEVATION

GR = GROUND ELEVATION

TD = TOTAL DEPTH

Figure 28. Geologic cross-section through points A-A' on Figure 27 map. (R.B.O.S.C., 1981)

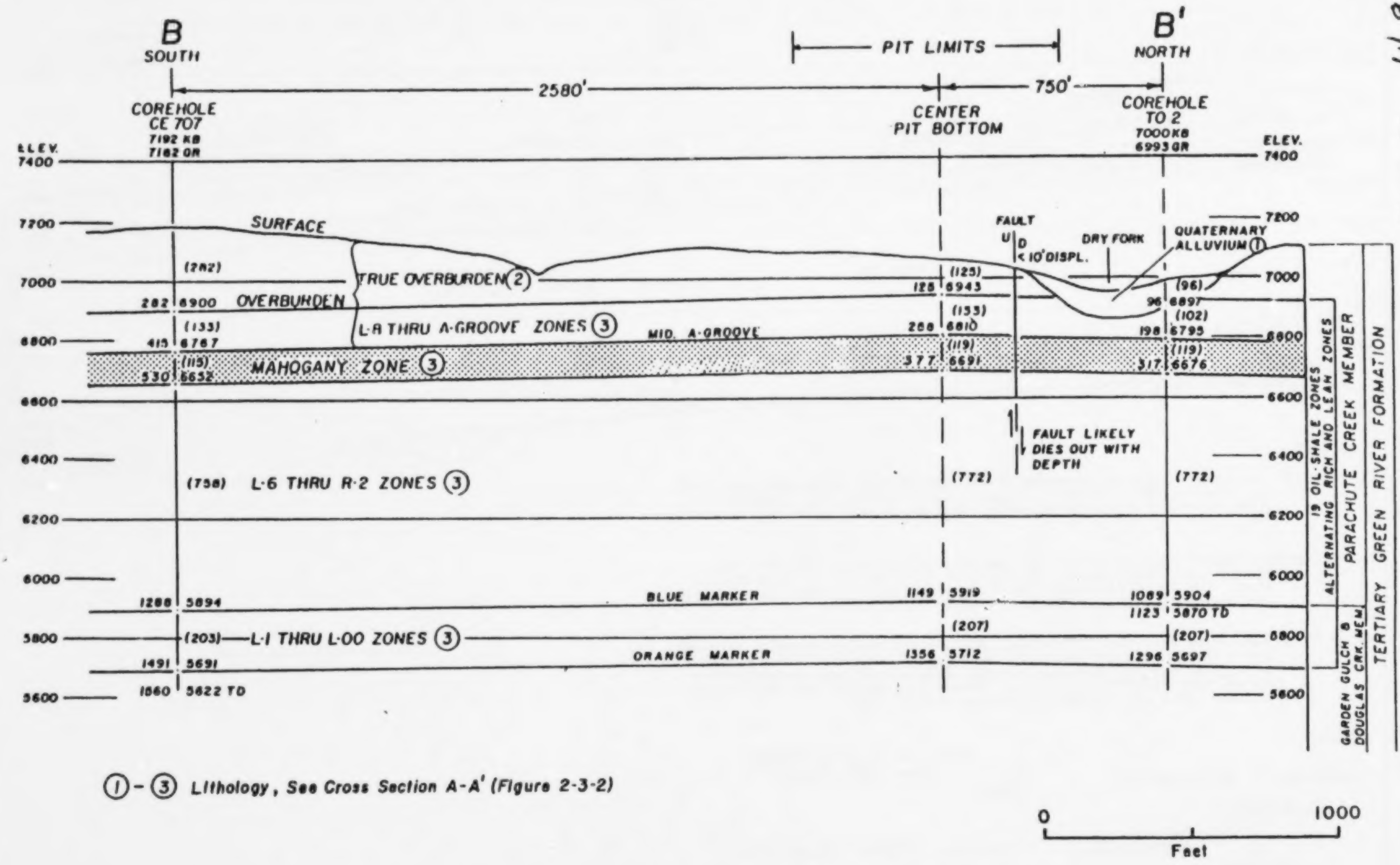
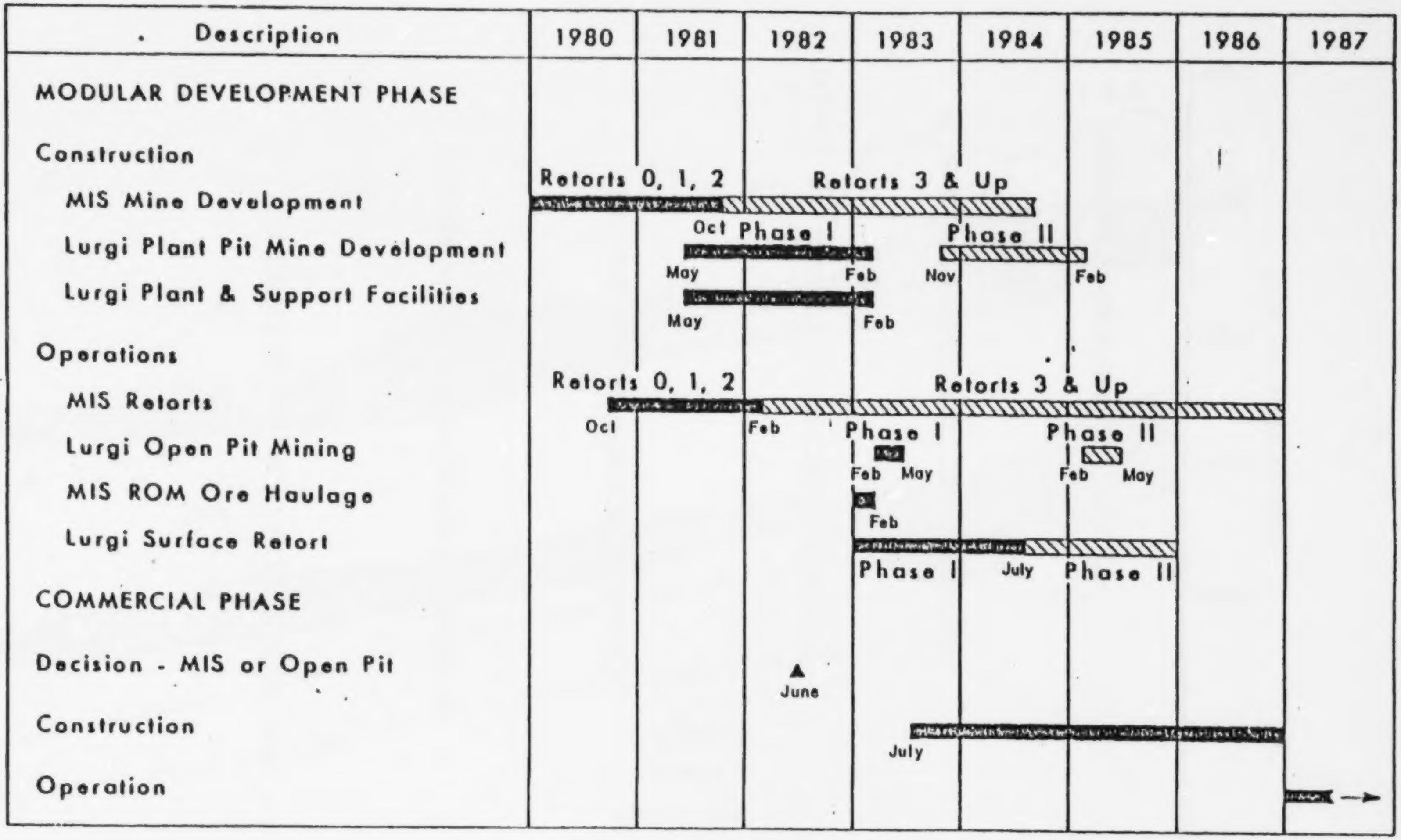


Figure 29. Geologic cross-section through points B-B' on Figure 27 map.
(R.B.O.S.C., 1981)



RBOSC Construction and Operation Schedule

RBOS Feb. 1981

Figure 30

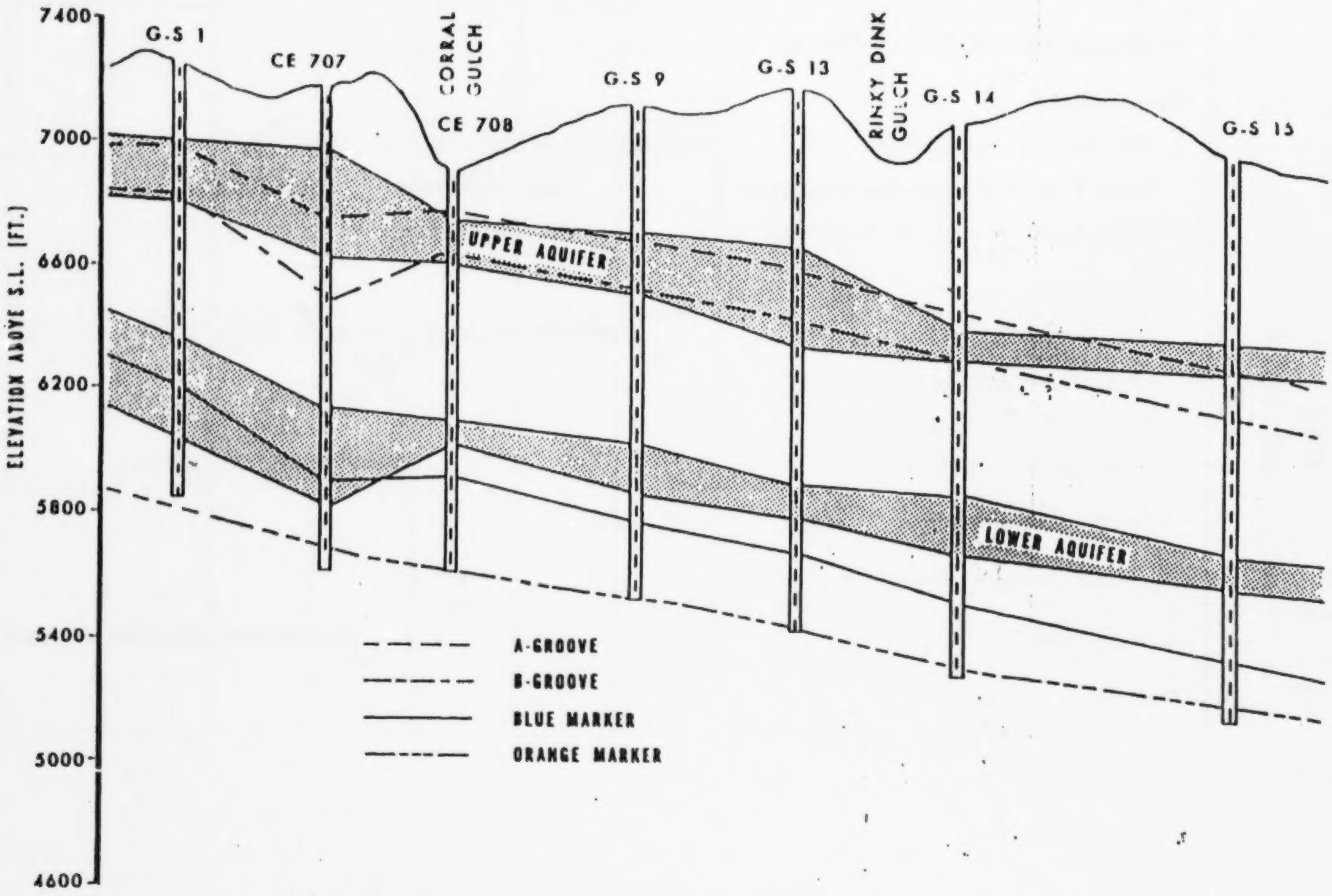
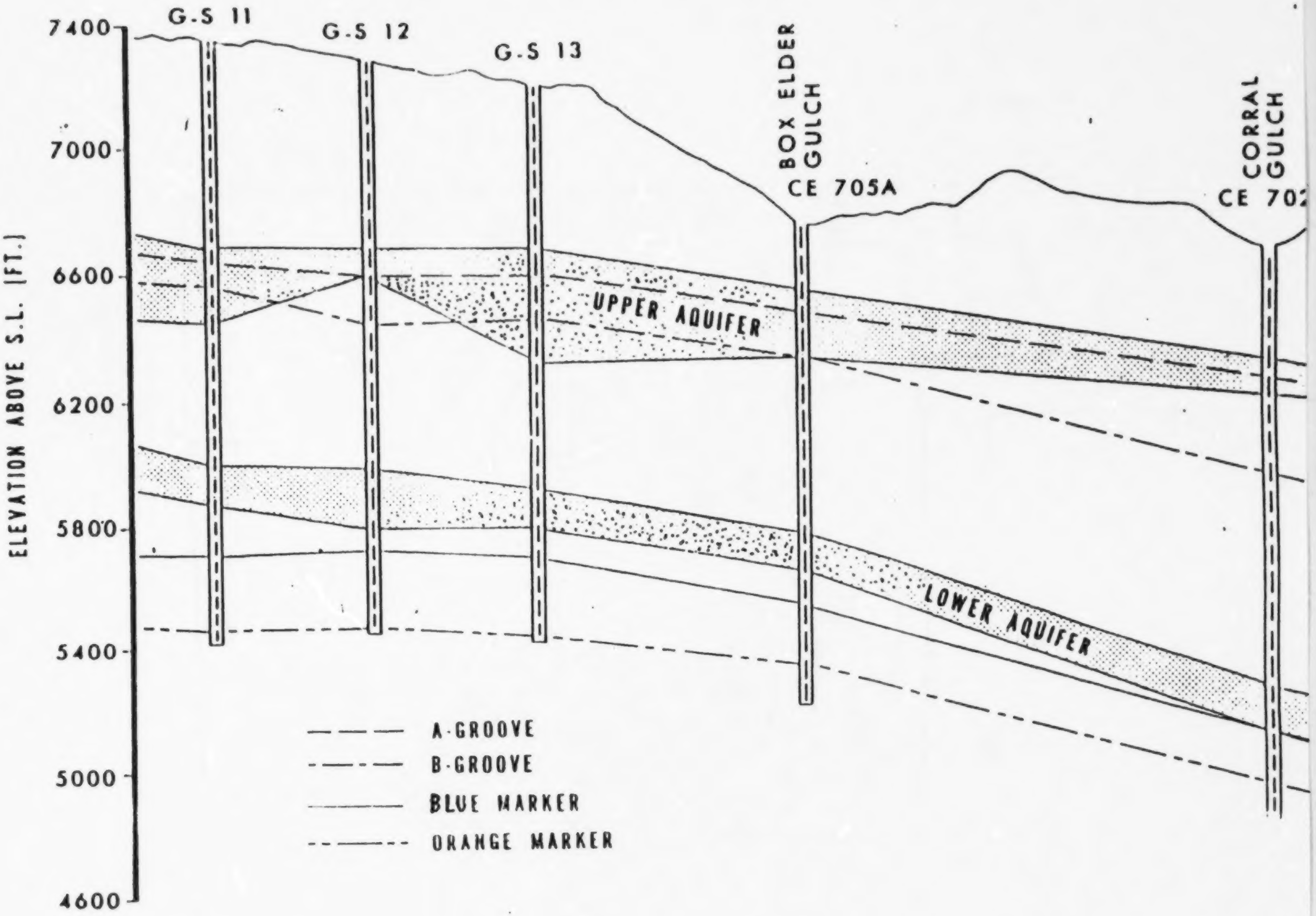


Fig. 31 UPPER AND LOWER BEDROCK AQUIFERS UNDER TRACT C-a

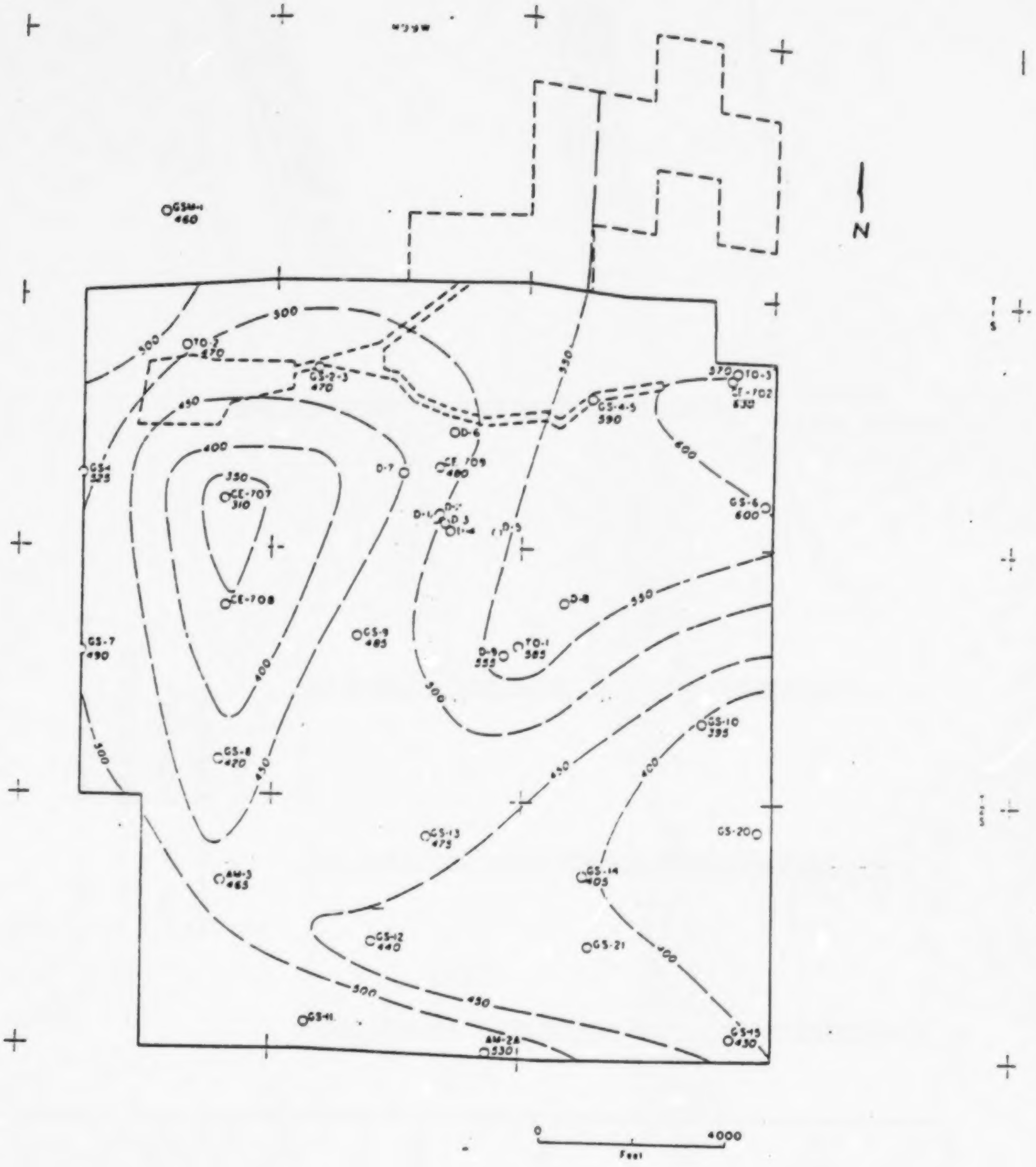
Figure 31



CROSS SECTION, UPPER AND LOWER BEDROCK AQUIFER

(R.B.O.S.C., 1977)

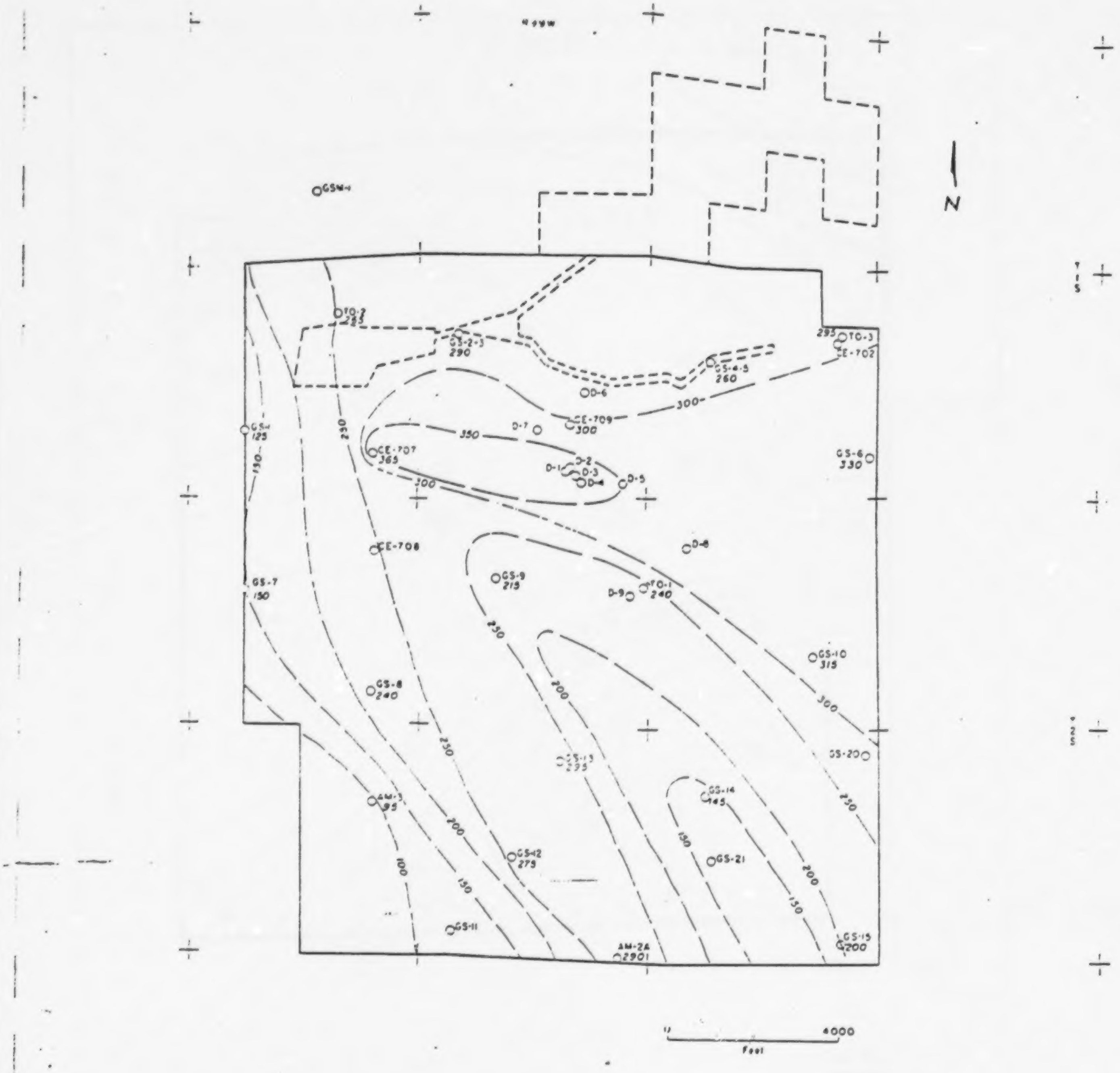
Figure 32



Isopach of Aquitard

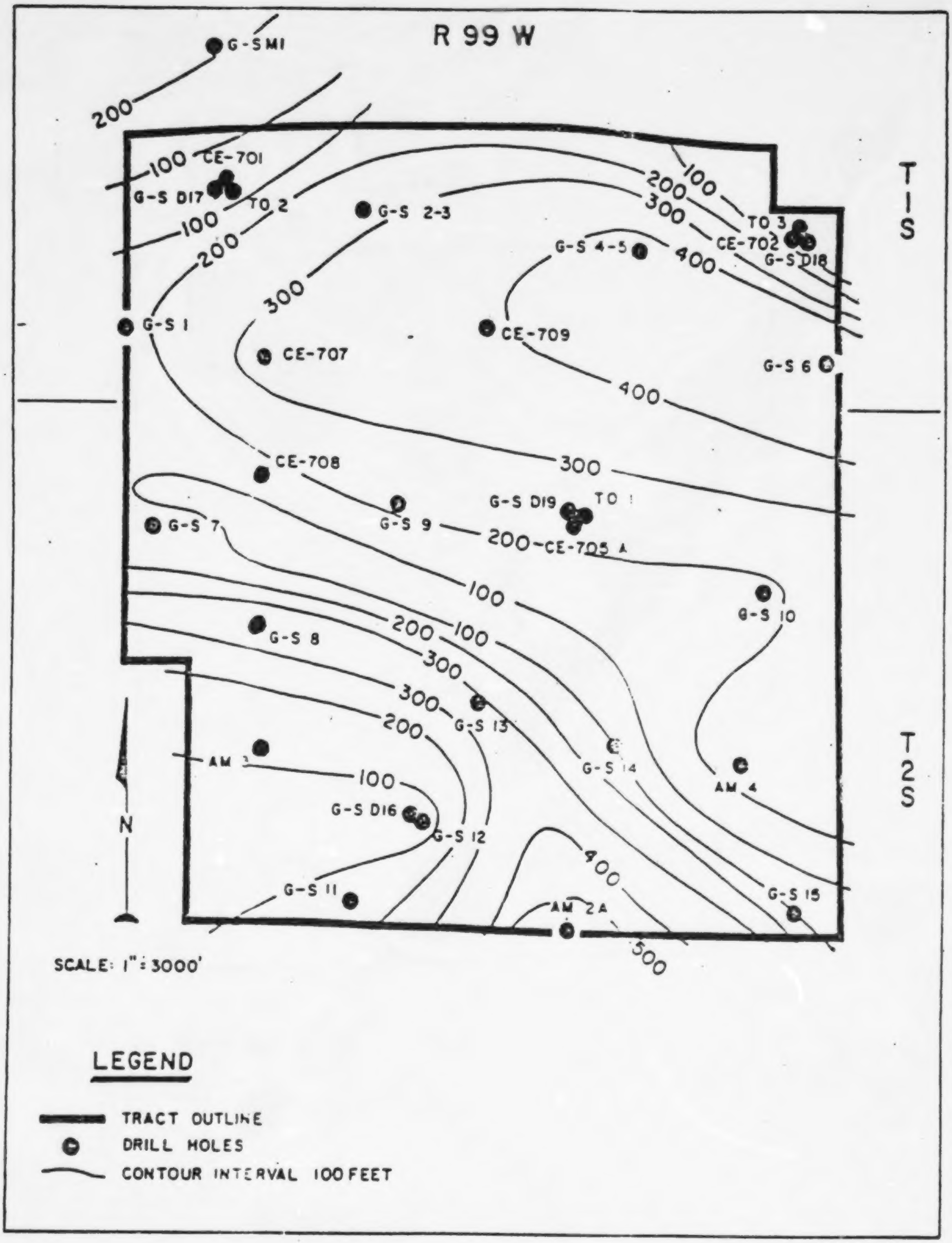
RBOS Feb. 1981

Figure 33



154 Isopach of Upper Aquifer
RBOS Feb. 1981

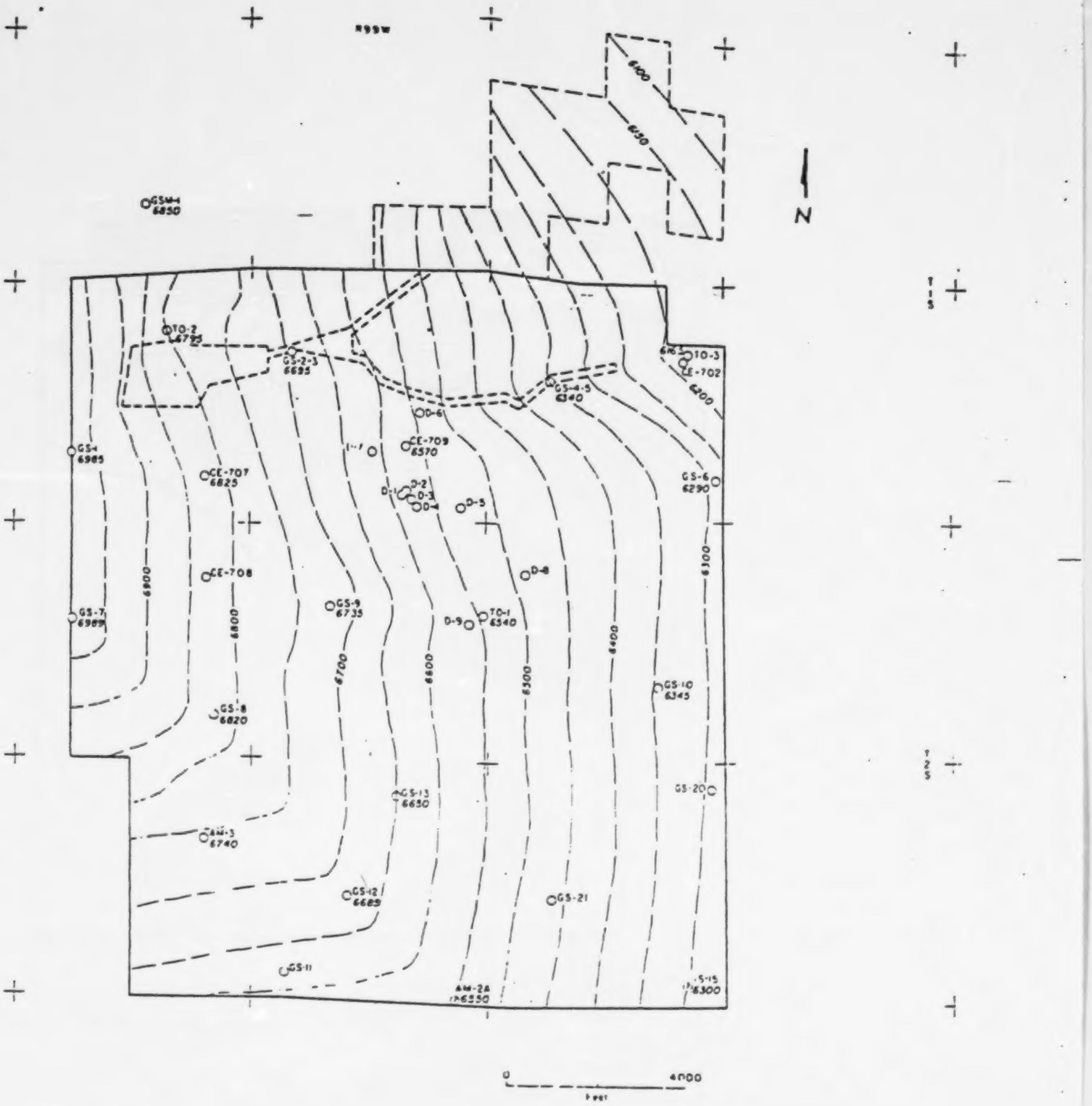
Figure 34



UPPER AQUIFER THICKNESS (ft)

RBOS Feb. 1977

Figure 35

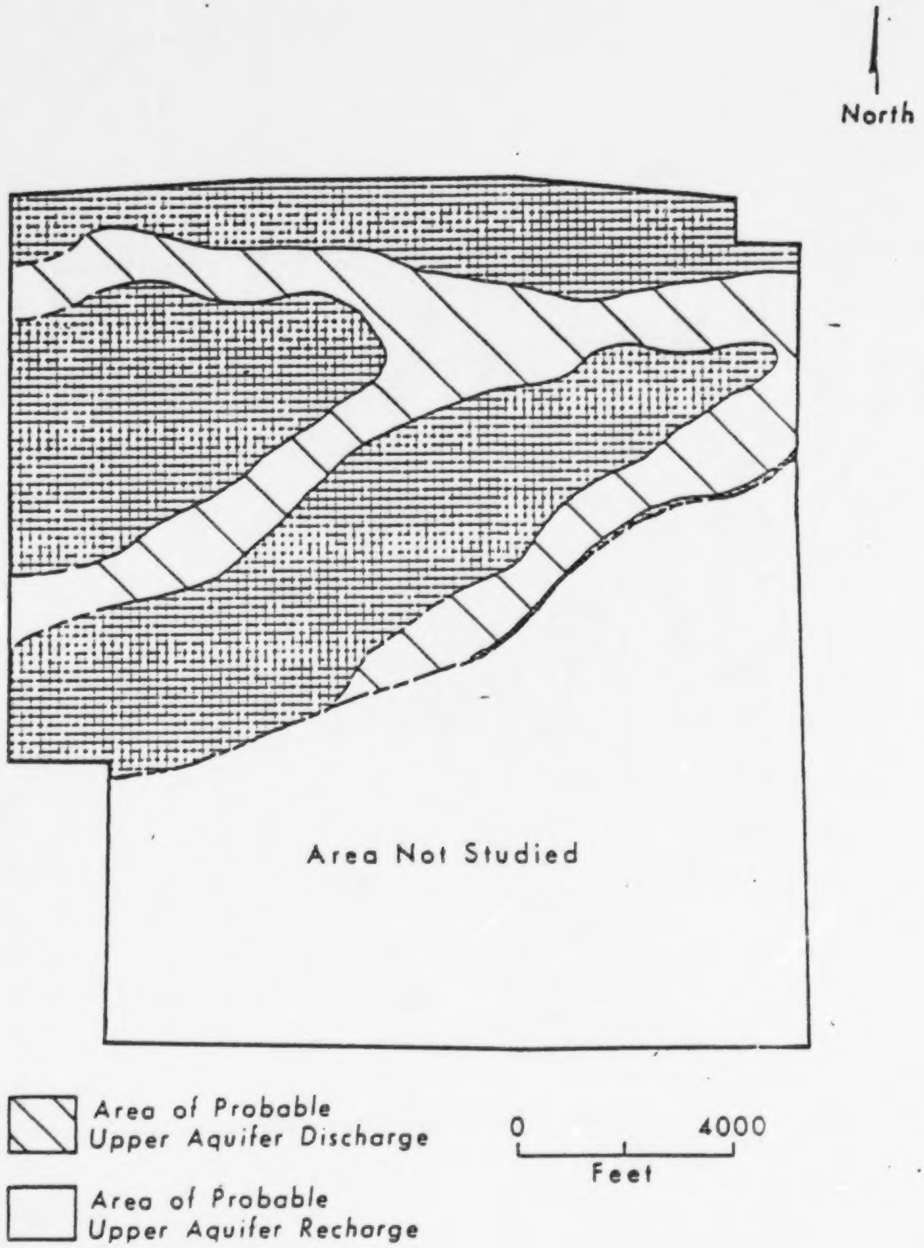


Topof Upper Aquifer

RBOS Feb. 1981

156

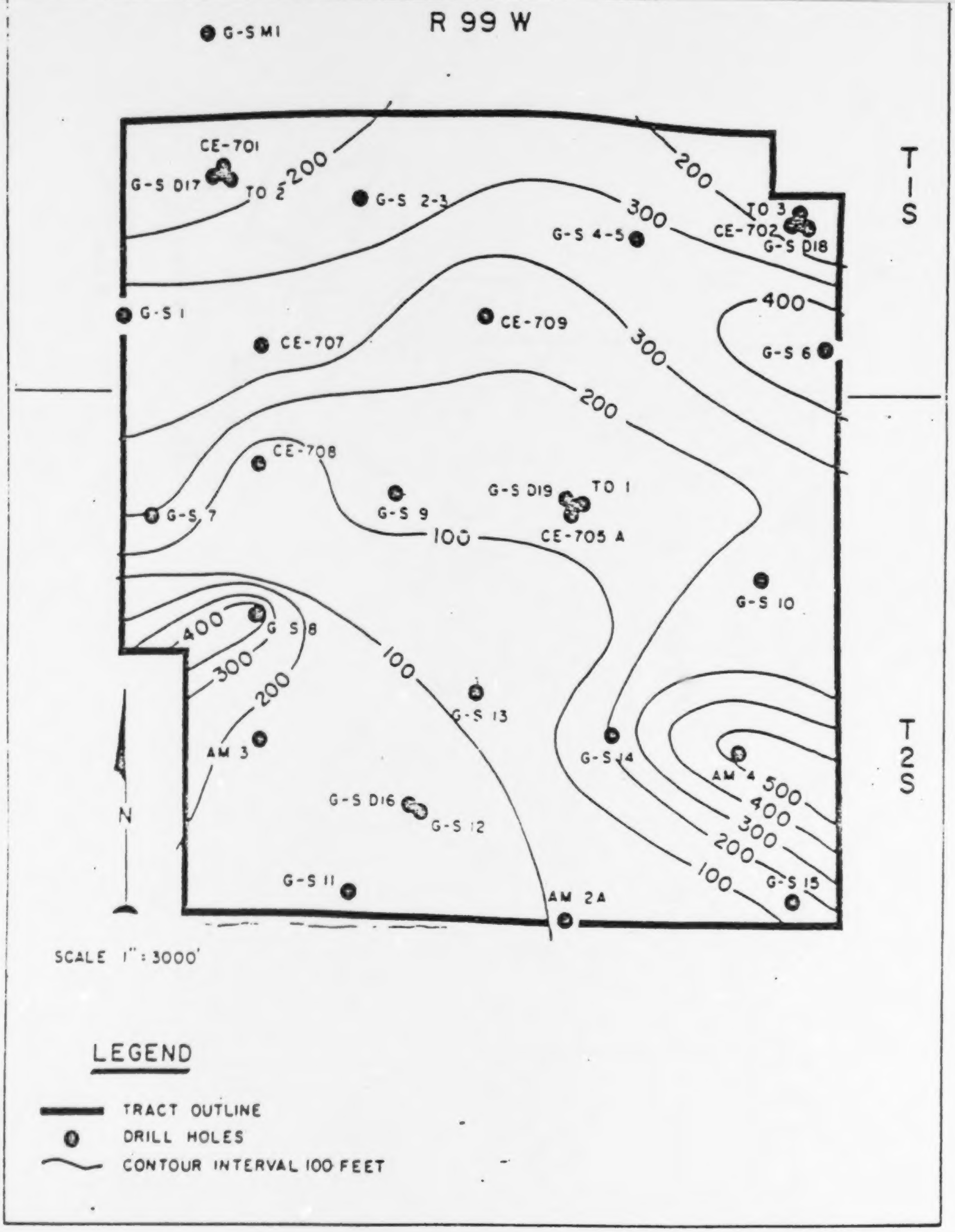
Figure 36


North
Area Not Studied
Area of Probable Upper Aquifer Discharge
Area of Probable Upper Aquifer Recharge
0
4000
Feet

Upper Aquifer Recharge and Discharge Areas

RBOS Feb. 1981

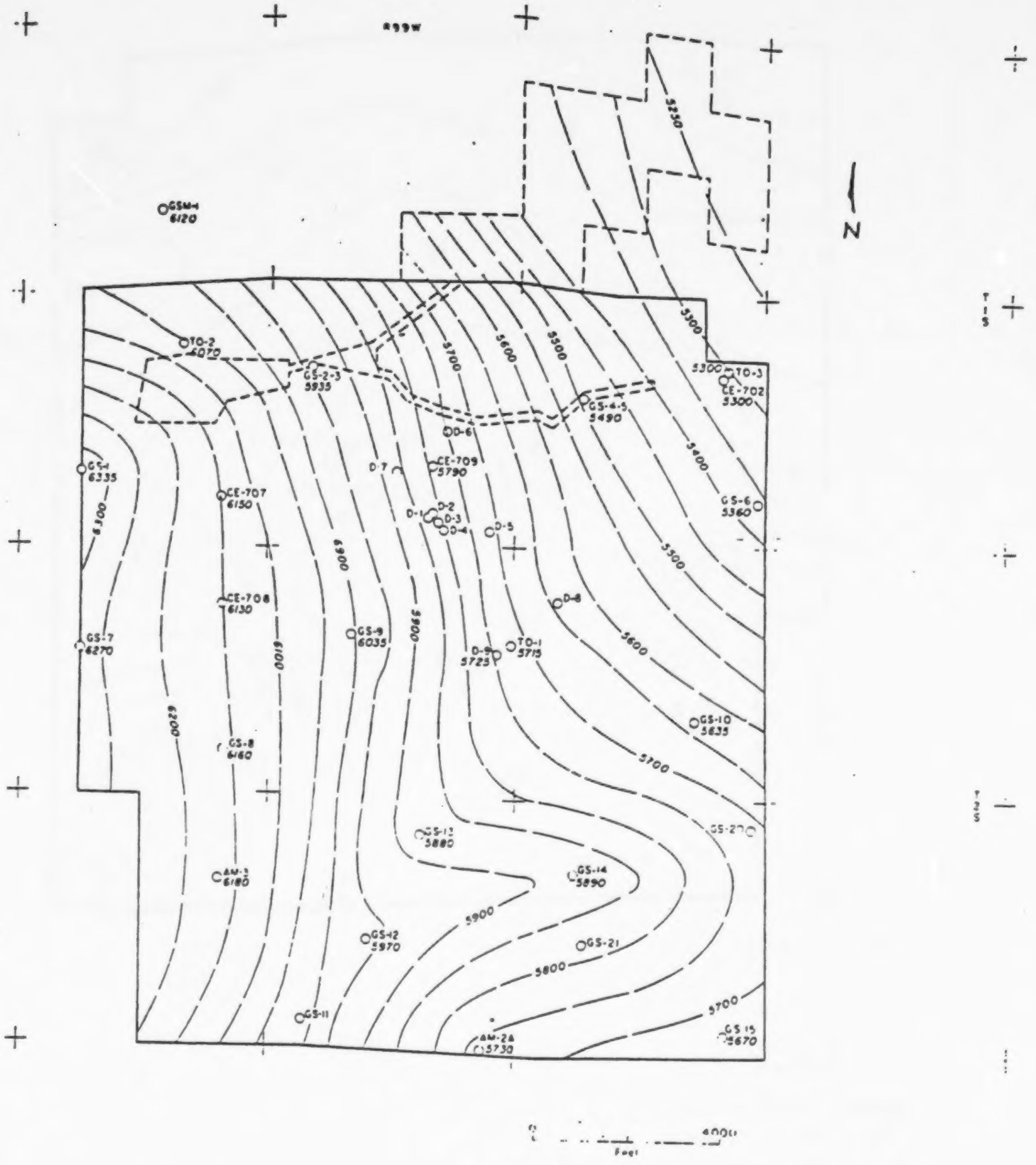
Figure 37



LOWER AQUIFER THICKNESS (ft)

RBOS Sept. 1977

Figure 38



Top of Lower Aquifer

RBOS Feb. 1981

Figure 39

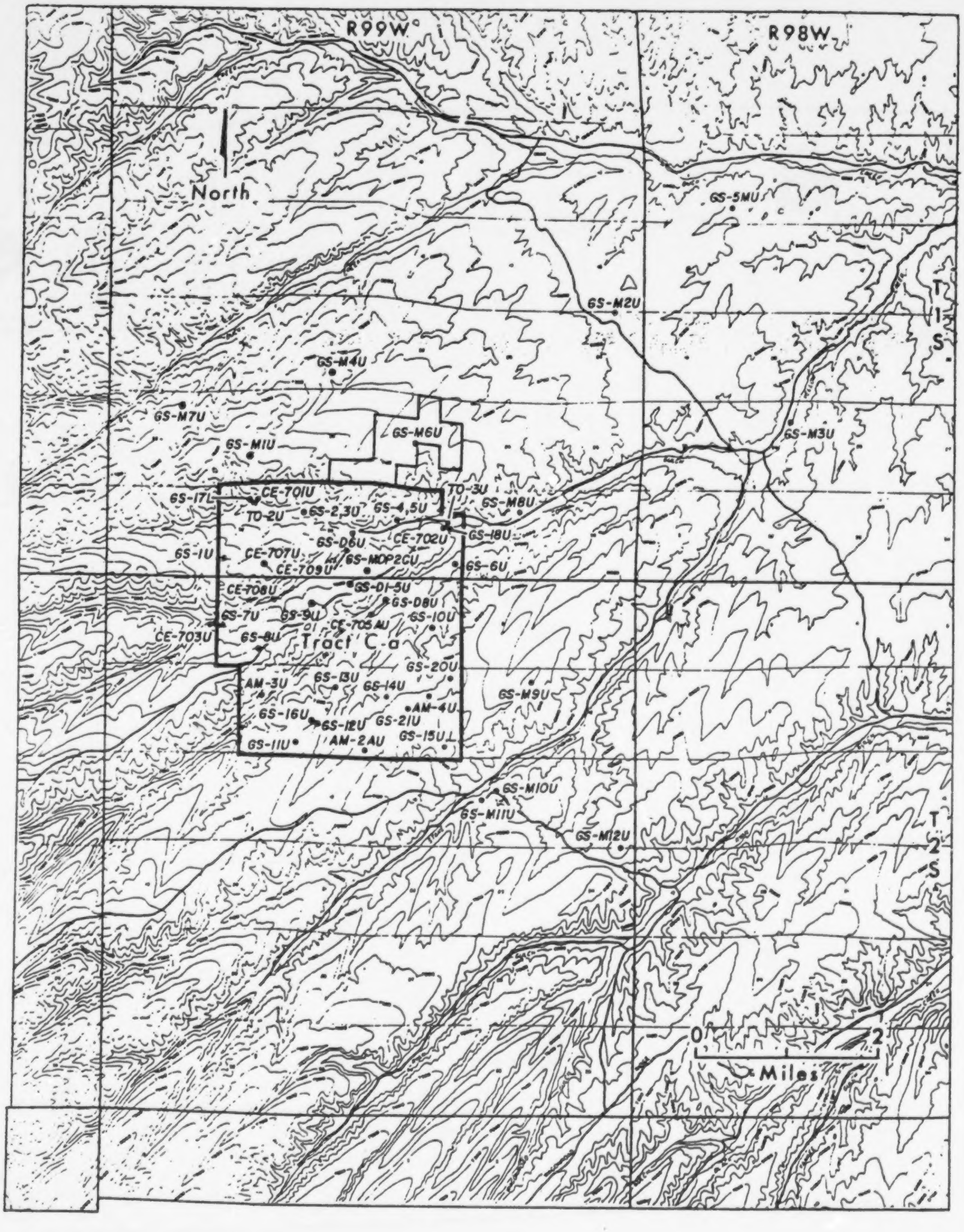
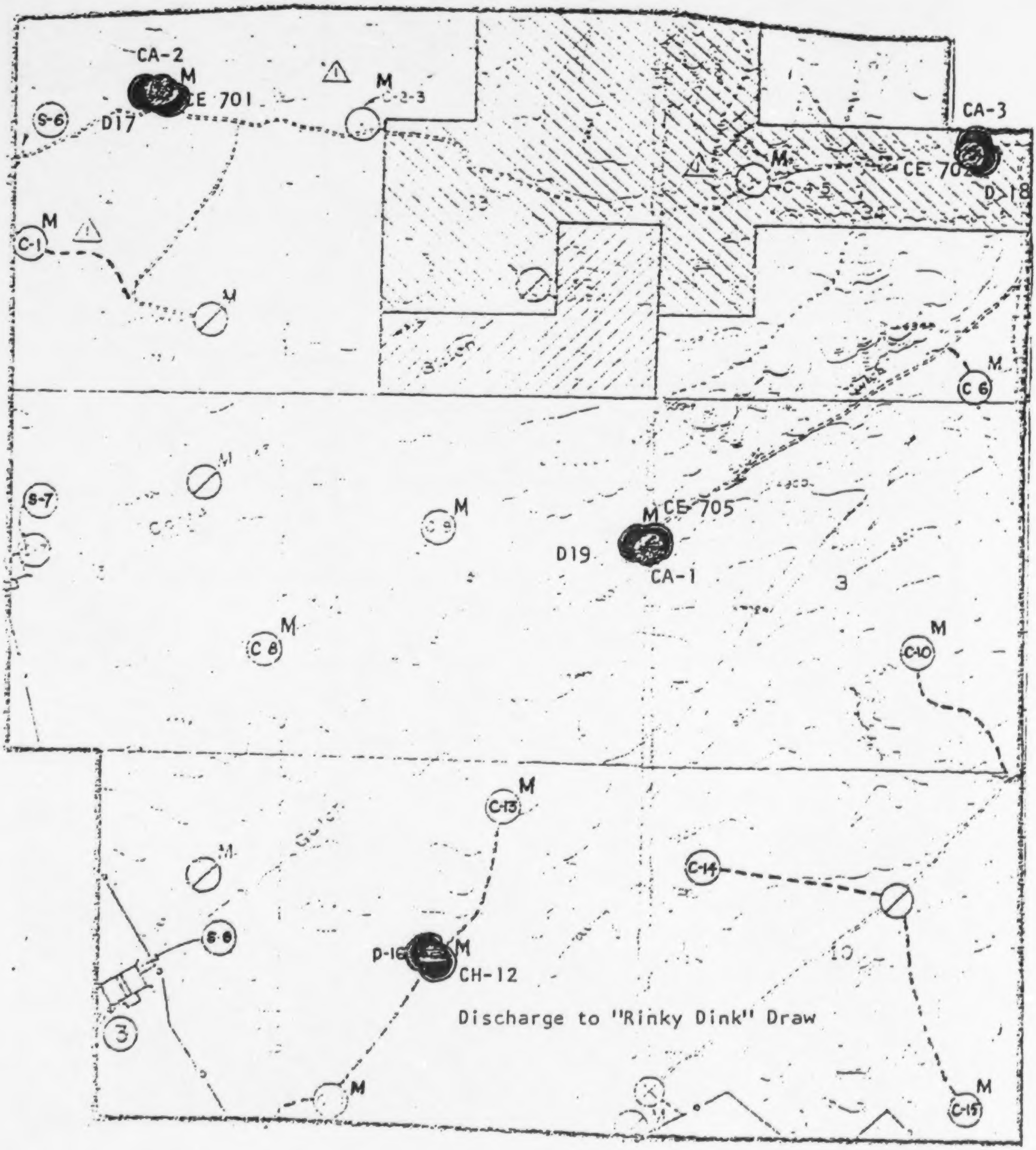


Figure 40
Deep Aquifer Monitoring Stations

160

TRACT C-a
LARGE DIAMETER
HOLE LOCATIONS



● Large Diameter Holes

● Upper Aquifer Pump Test Holes

○ Monitor Holes

Figure 41

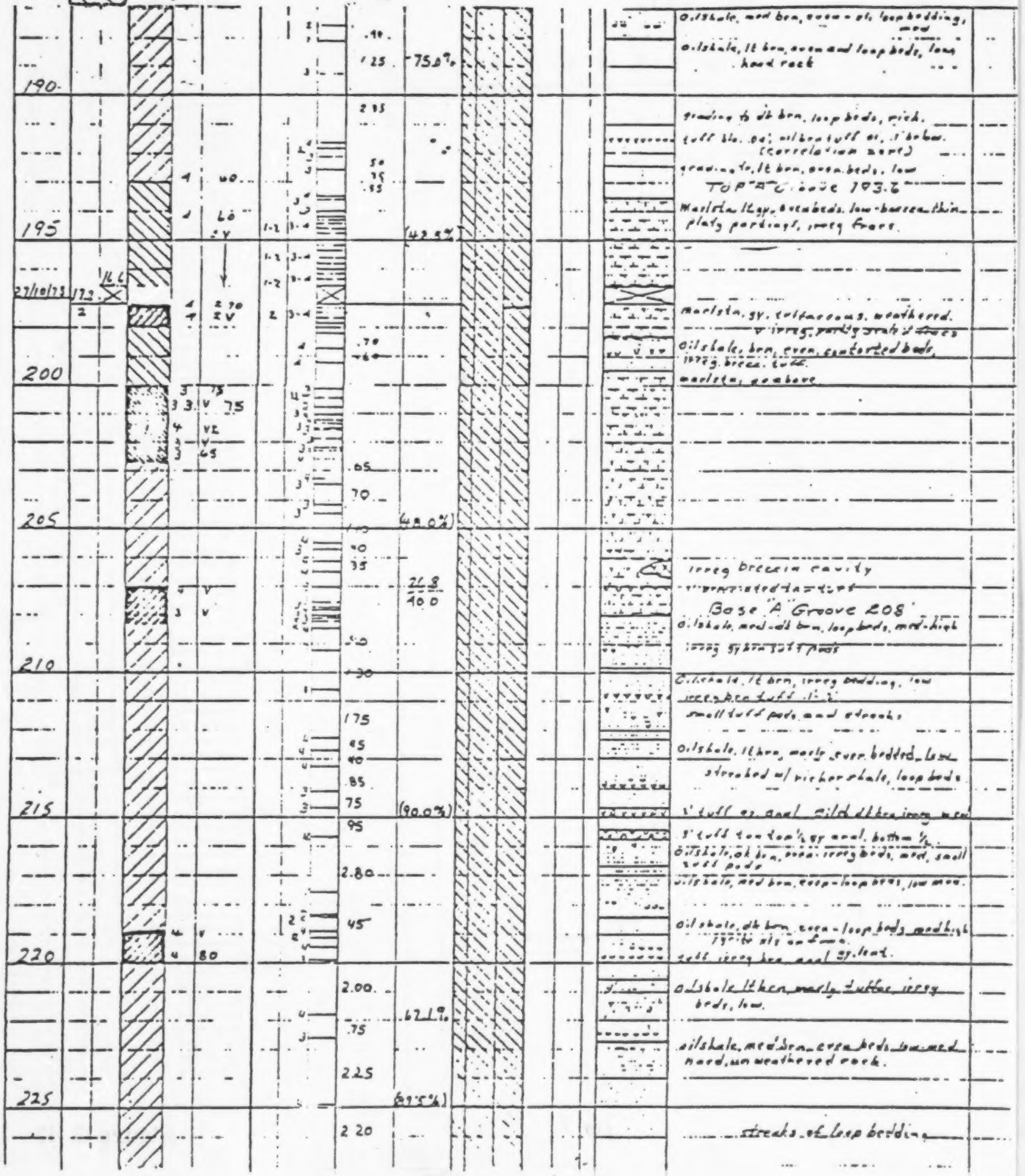
CORE HOLE: C-A-2

LOCATION: SE NW NE, Sec. 32, T.1S., R.99W.
Rio Blanco County, Colorado

JOINT, FRACTURE, AND PARTING SPACING

1	▨	Very close	< 1.5"
2.	▨	Close	1.5"- 1'
3.	▨	Moderately close	1'- 3'
4.	▨	Wide	3'-10'
5.	▨	Very wide	> 10'

RQD Log Figure 42


190
195
27/10/75
200
205
210
215
220
225
75.0%
42.5%
48.0%
26.8
40.0
90.0%
67.1%
89.5%
oilshale, med brn, even - sl. loop bedding, med
oilshale, lt brn, even and loop beds, low
hard rock
grading to dk brn, loop beds, rich.
tuff blu. .04'; oil brn tuff at .1' below. (correlation zone)
grading to, lt brn, even beds, low
TOP "A" Groove 193.6
Marlstn. lt gy, even beds. low - barren, thin - platy partings, irreg fract.
marlstn, gy. tuffaceous, weathered.
oilshale, brn, even, contorted beds, irreg. brecc. tuff.
marlstn, as above
irreg breccia cavity
Base "A" Groove 208
oilshale, med-dk brn, loop beds, med-high
oilshale, lt brn, irreg bedding, low
small tuff pods and streaks
oilshale, lt brn, mostly even bedded, low
streaked w/ richer shale, loop beds
oilshale, med brn, even-loop beds, low med.
oilshale, dk brn, even - loop beds, med high
oilshale lt brn, marly, tuffac. irreg beds, low.
oilshale, med brn, even beds, low-med hard, unweathered rock.
streaks of loop bedding

162

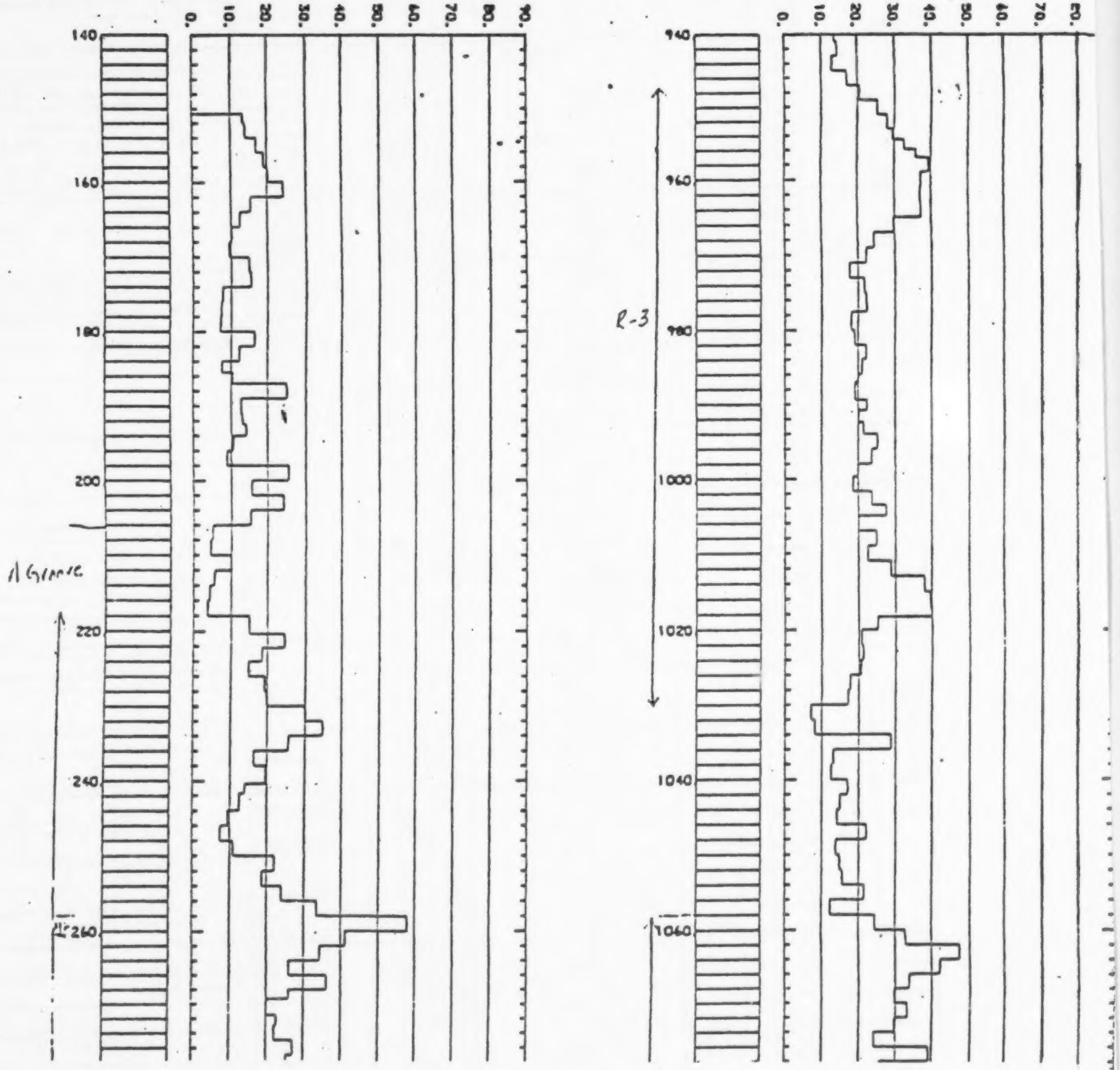
COMPANY Cameron Engrs.

WELL NO. CE-701

STATE Colorado COUNTY Rio Blanco

T. 1S R. 99W S. 32

1150' FNL - 1038' FEL
Sur. 6997



163

FISCHER ASSAY

Figure 43

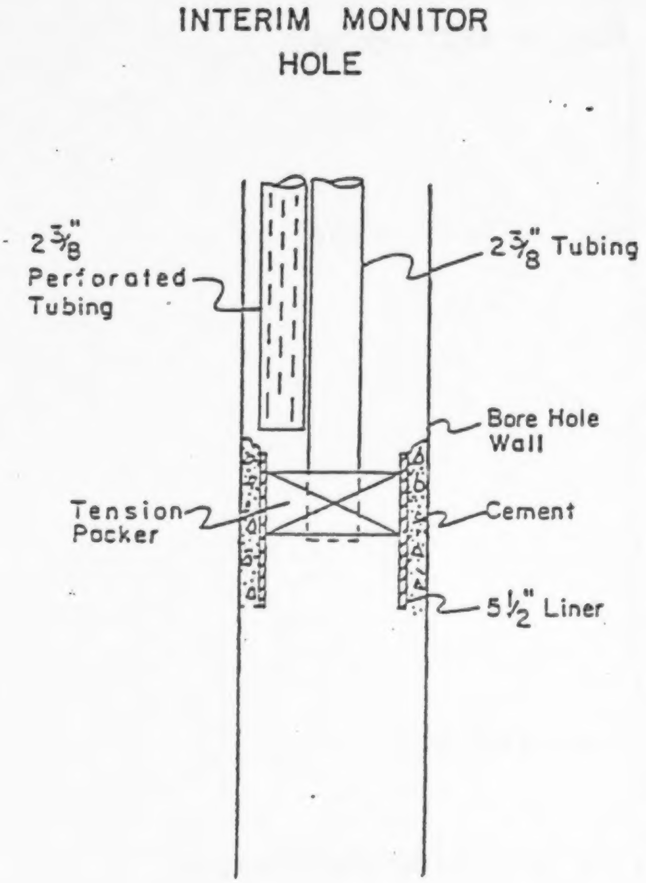


FIGURE 1

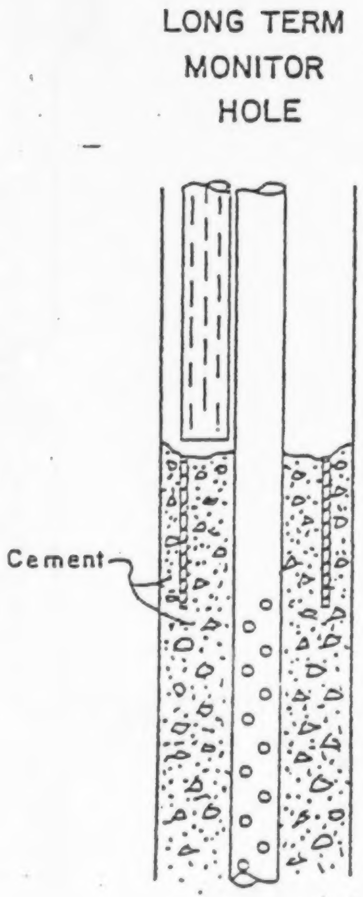
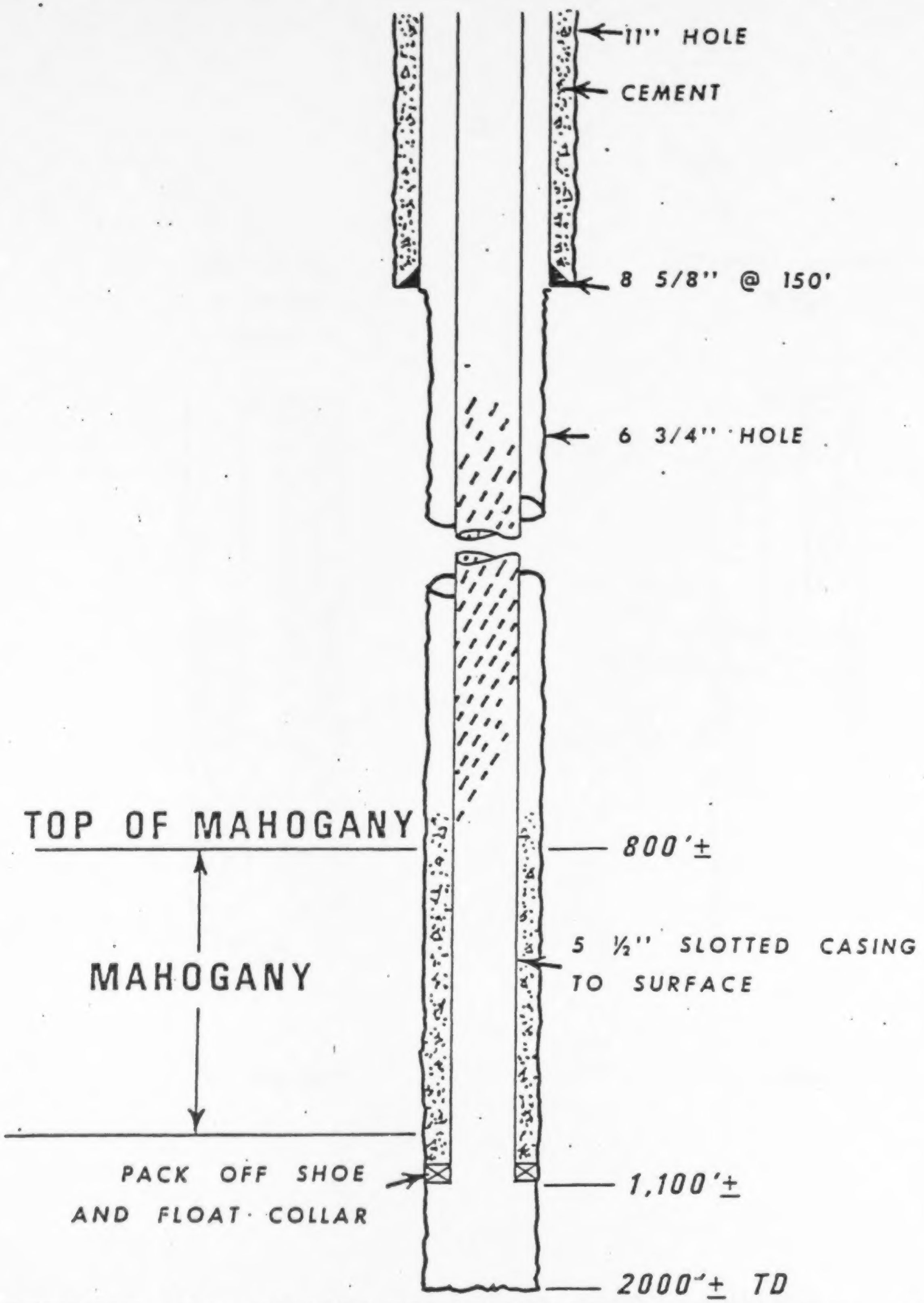


FIGURE 2

Area Oil Shale Office, Grand Junction, CO

Figure 44



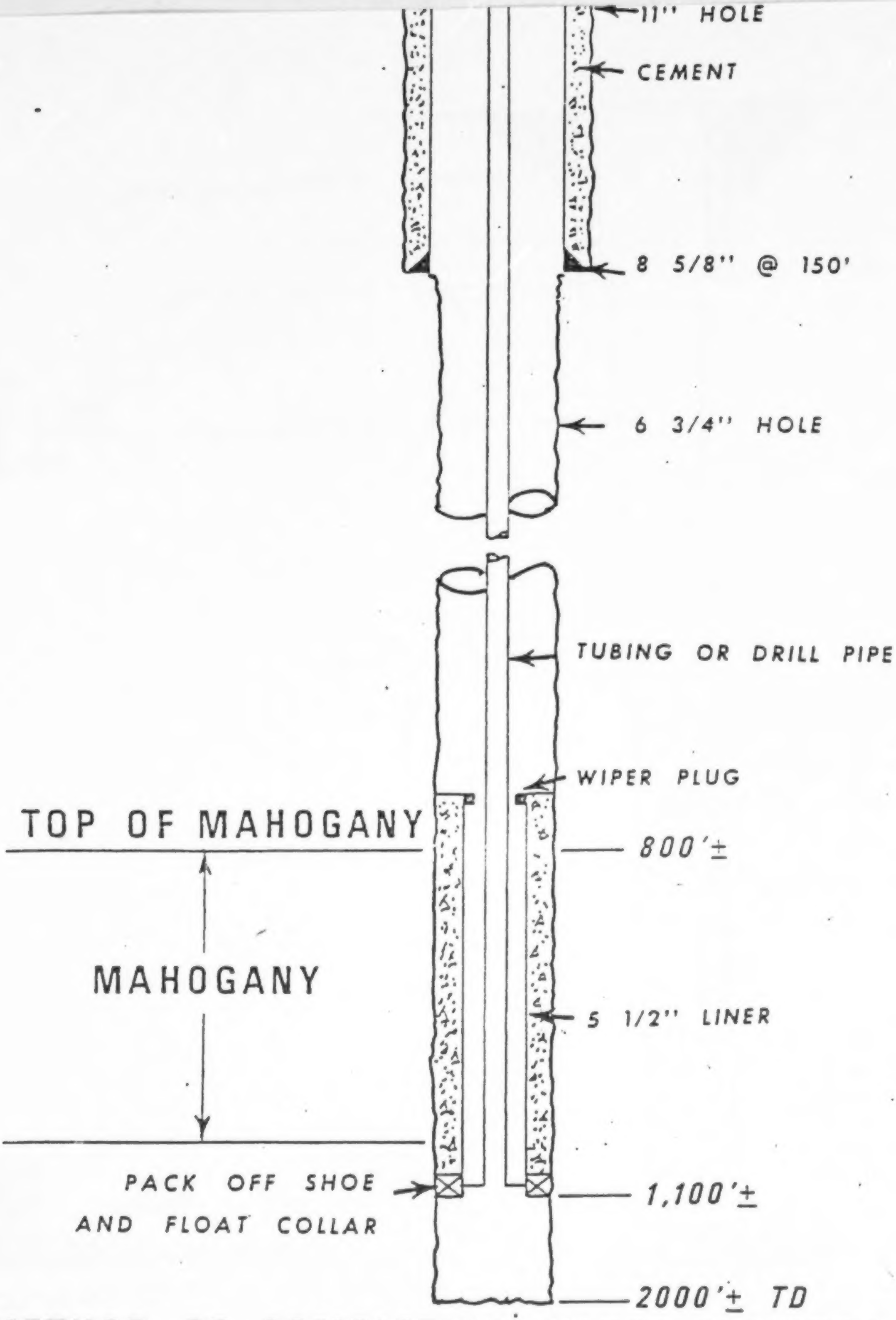
METHOD OF COMPLETING WATER MONITOR HOLES USING LONG STRING OF CASING

OIL SHALE TRACT C-A

Figure 45

Gulf Oil Jan. 1974

165



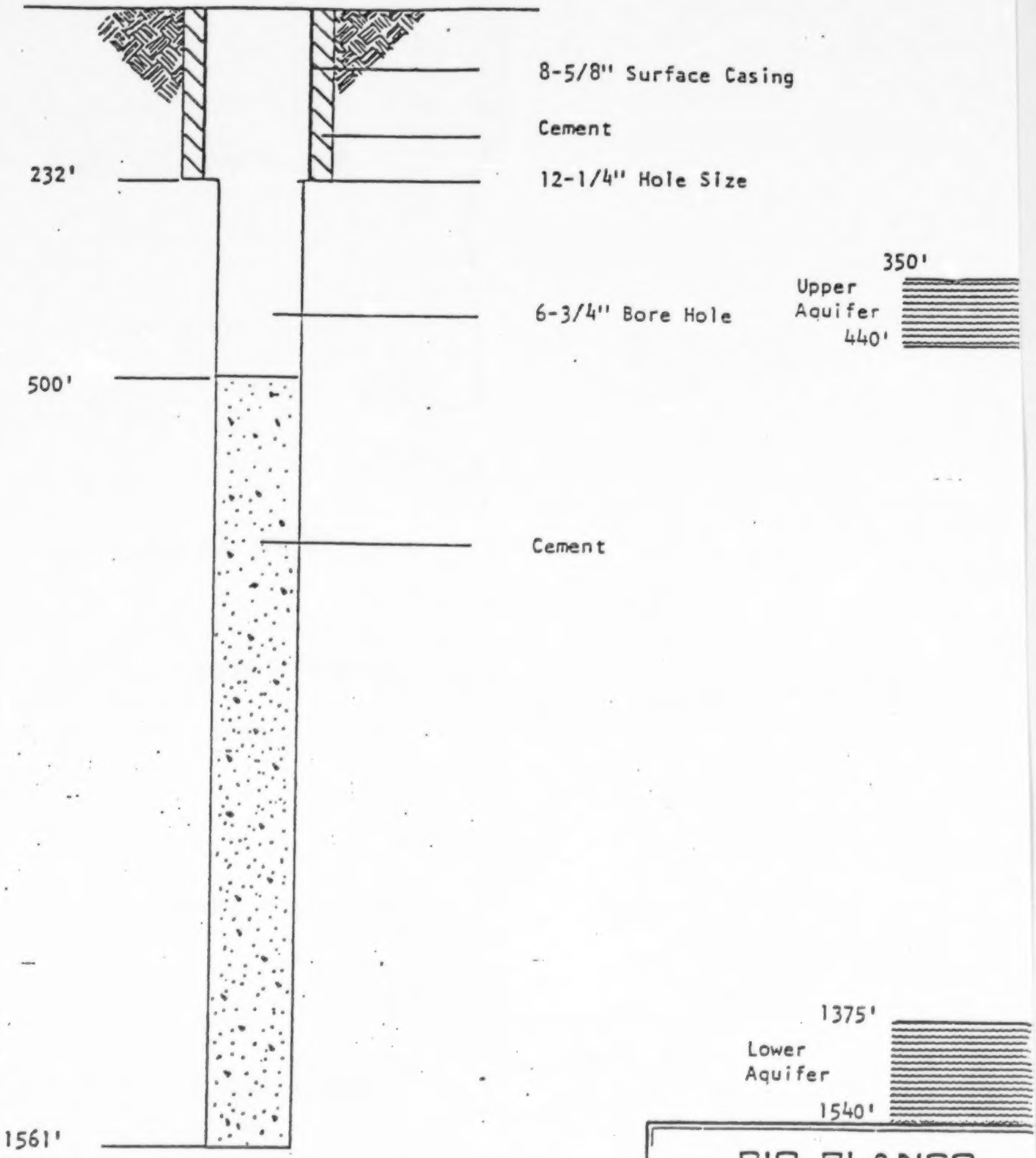
METHOD OF COMPLETING WATER MONITOR HOLES USING LINER

OIL SHALE TRACT C-A

Figure 46

Gulf Oil Jan. 1974

Figure 46



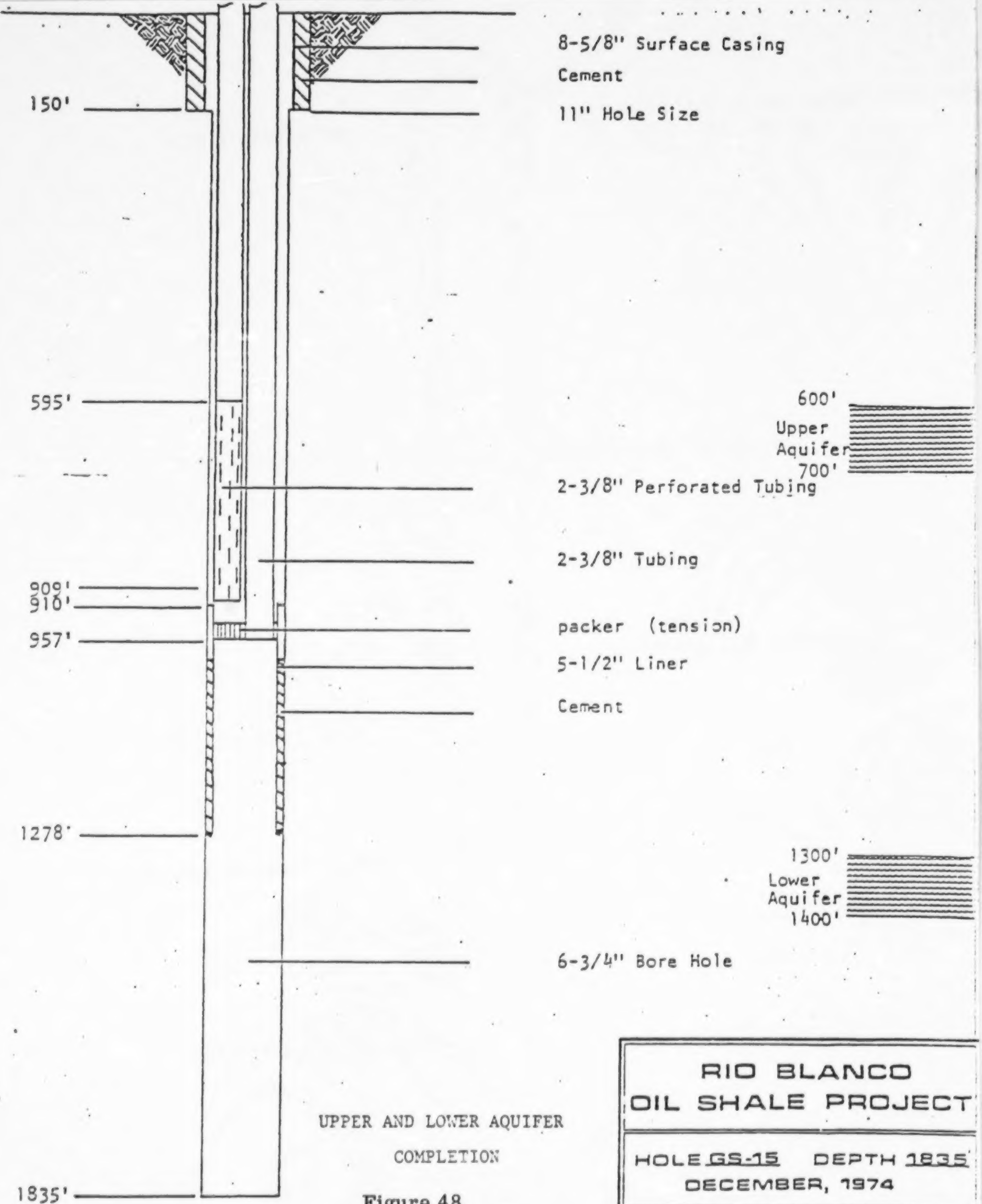
UPPER AQUIFER COMPLETION

VERITICAL SCALE 1"-200'
HORIZONTAL SCALE 1"-1'0"

RIO BLANCO
OIL SHALE PROJECT

HOLE TO-3 DEPTH 1561
DECEMBER, 1974

WRIGHT WATER ENGINEERS INC.
ENGINEERING CONSULTANTS
[illegible]
DENVER COLORADO [illegible]



UPPER AND LOWER AQUIFER

COMPLETION

Figure 48

RIO BLANCO
OIL SHALE PROJECT

HOLE GS-15 DEPTH 1835'
DECEMBER, 1974

WRIGHT WATER ENGINEERS INC
ENGINEERING CONSULTANTS
3420 ALCOTT STREET
DENVER COLORADO 80211

VERITICAL SCALE 1"-200'
HORIZONTAL SCALE 1"-1'-0"

Figure 48

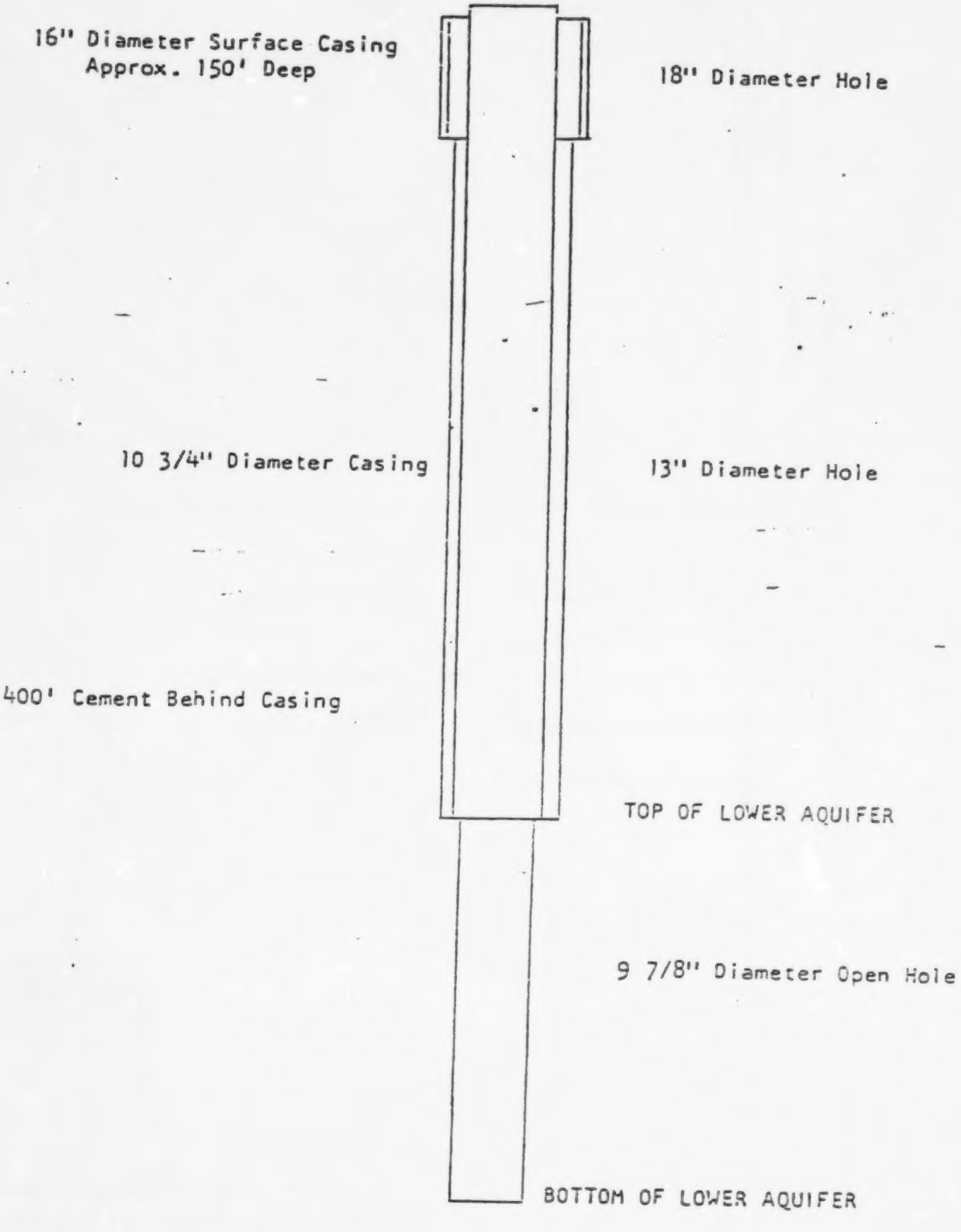
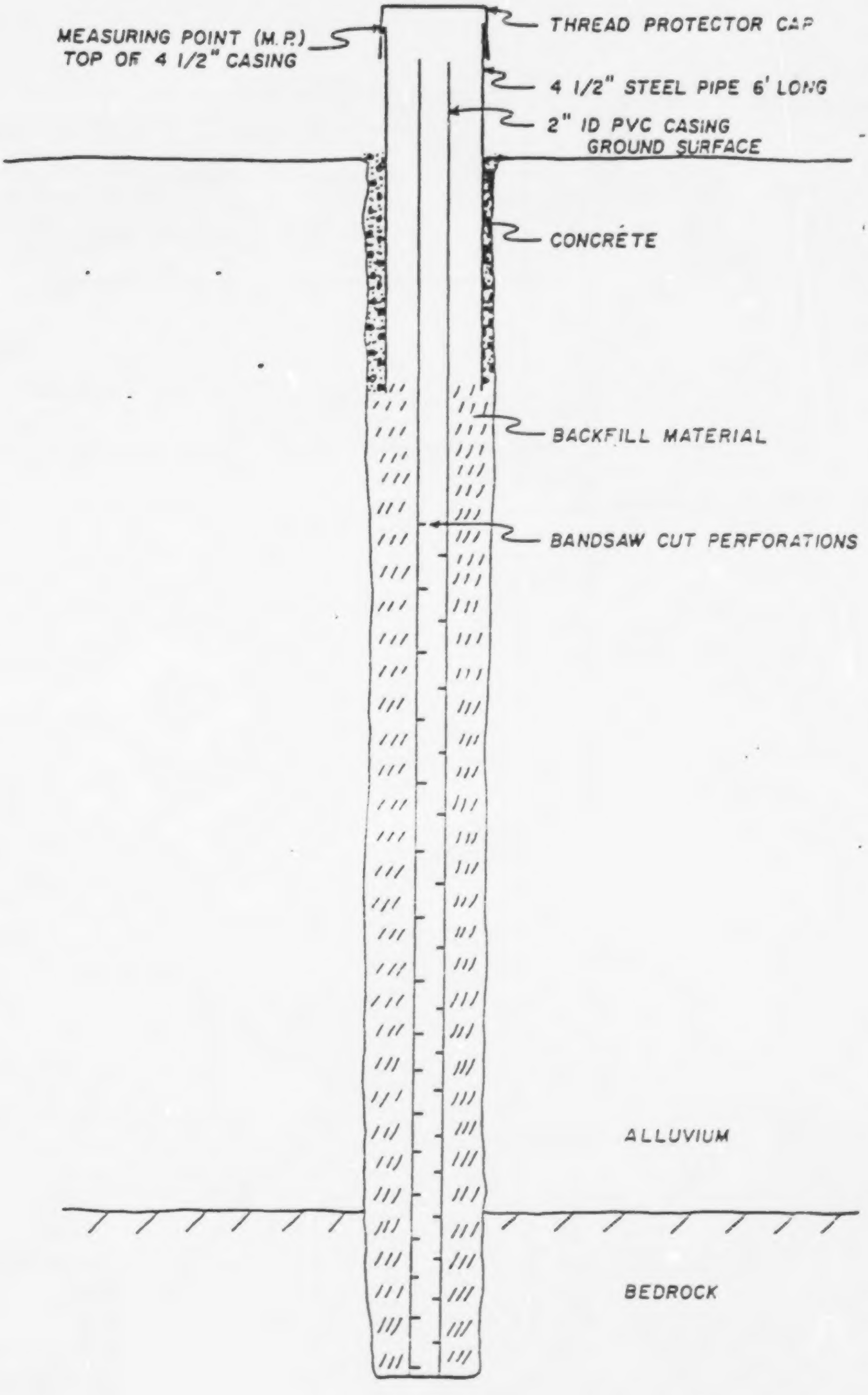

16" Diameter Surface Casing
Approx. 150' Deep
18" Diameter Hole
10 3/4" Diameter Casing
13" Diameter Hole
400' Cement Behind Casing
TOP OF LOWER AQUIFER
9 7/8" Diameter Open Hole
BOTTOM OF LOWER AQUIFER

Figure 49

GENERAL CONSTRUCTION OF AQUIFER TEST WELLS

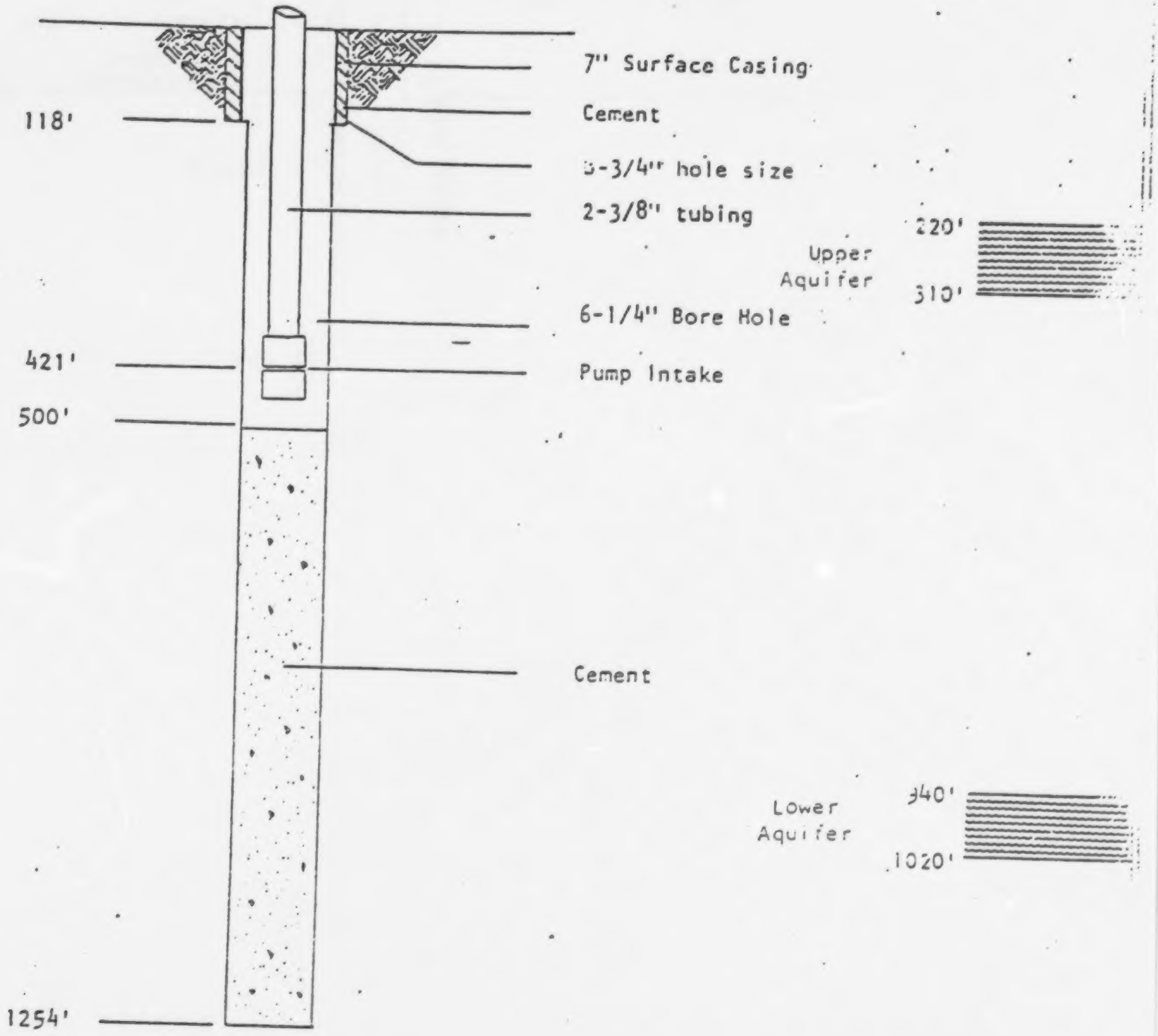
NOT TO SCALE



RBOS Oct. 1974/Feb. 1975

Figure 50

Pump Installation 15 HP



RIO BLANCO
OIL SHALE PROJECT

HOLE CS-701 DEPTH 1254
FEBRUARY 1975

WRIGHT WATER ENGINEERS INC
ENGINEERING CONSULTANTS
[illegible] ALCOTT STREET
DENVER COLORADO [illegible]

ERTICAL SCALE 1"-200'
ORIZONTAL SCALE 1"-1-0"

171

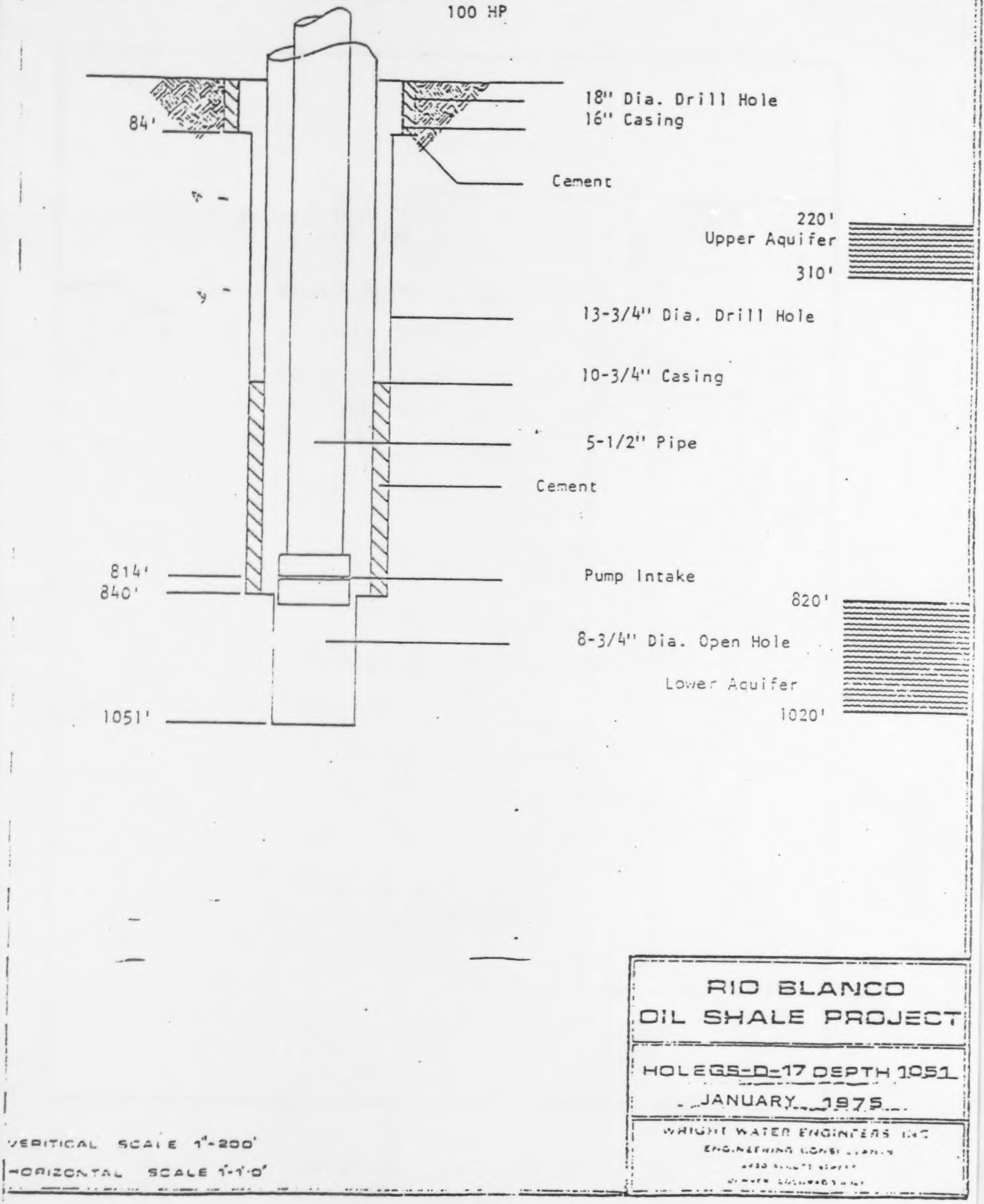
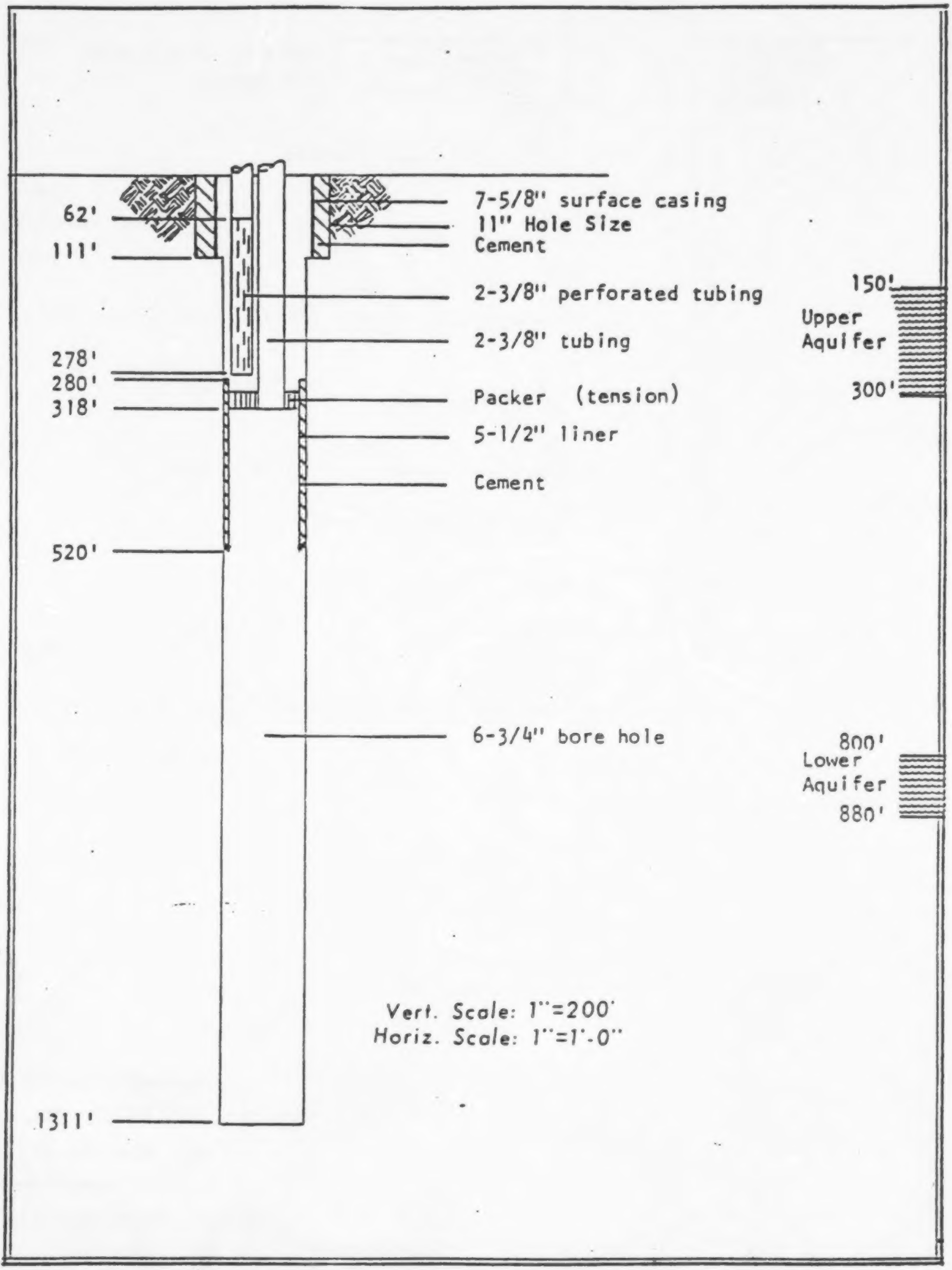

100 HP
18" Dia. Drill Hole
16" Casing
84'
Cement
220'
Upper Aquifer
310'
13-3/4" Dia. Drill Hole
10-3/4" Casing
5-1/2" Pipe
Cement
814'
840'
Pump Intake
820'
8-3/4" Dia. Open Hole
Lower Aquifer
1020'
1051'
RIO BLANCO
OIL SHALE PROJECT
HOLE GS-D-17 DEPTH 1051
JANUARY 1975
WRIGHT WATER ENGINEERS INC
ENGINEERING CONSULTANTS
VERITICAL SCALE 1"-200'
HORIZONTAL SCALE 1"-1'-0"

Figure 52

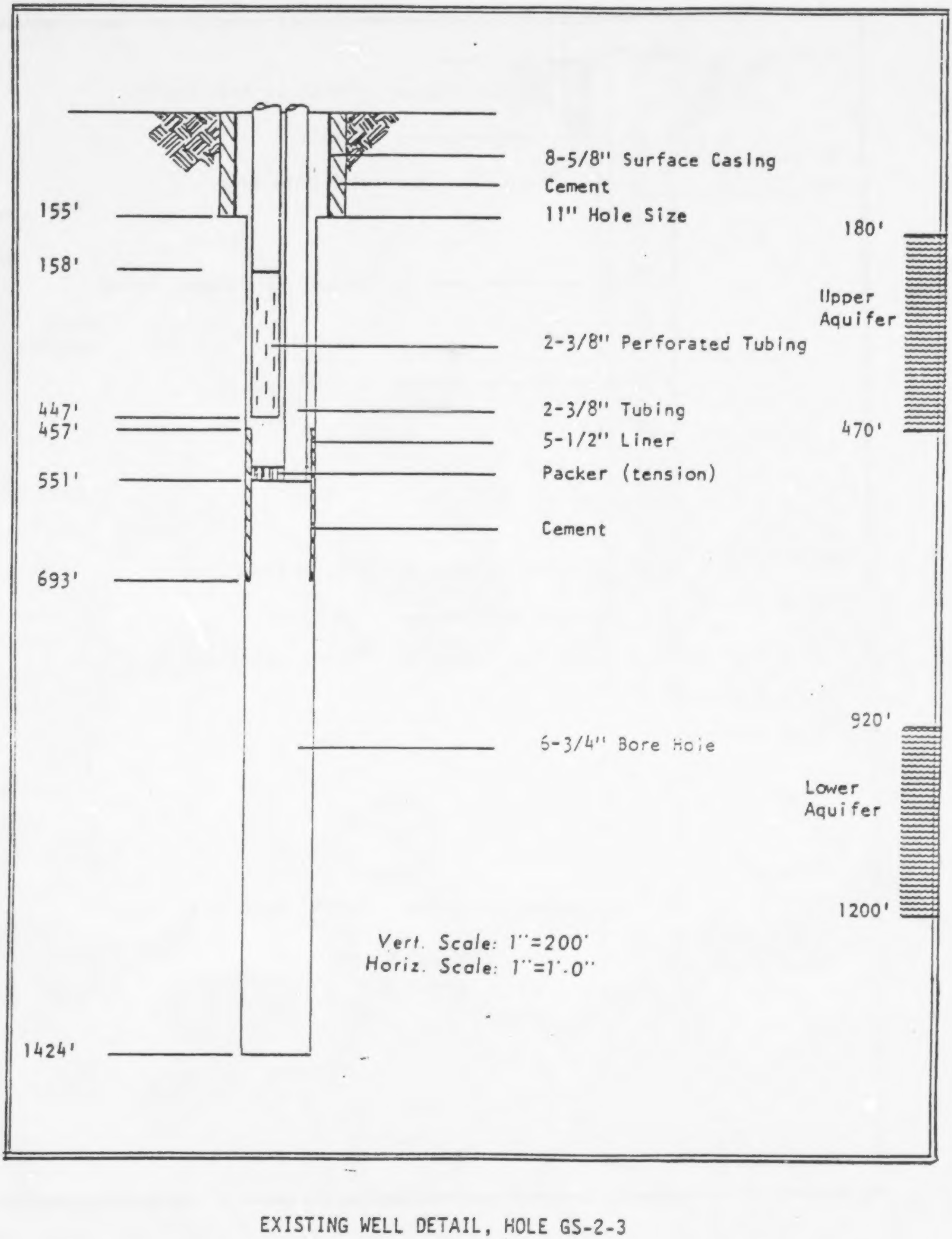


EXISTING WELL DETAIL, HOLE CE-708

RBOS Dept. 1977

173

Figure 53

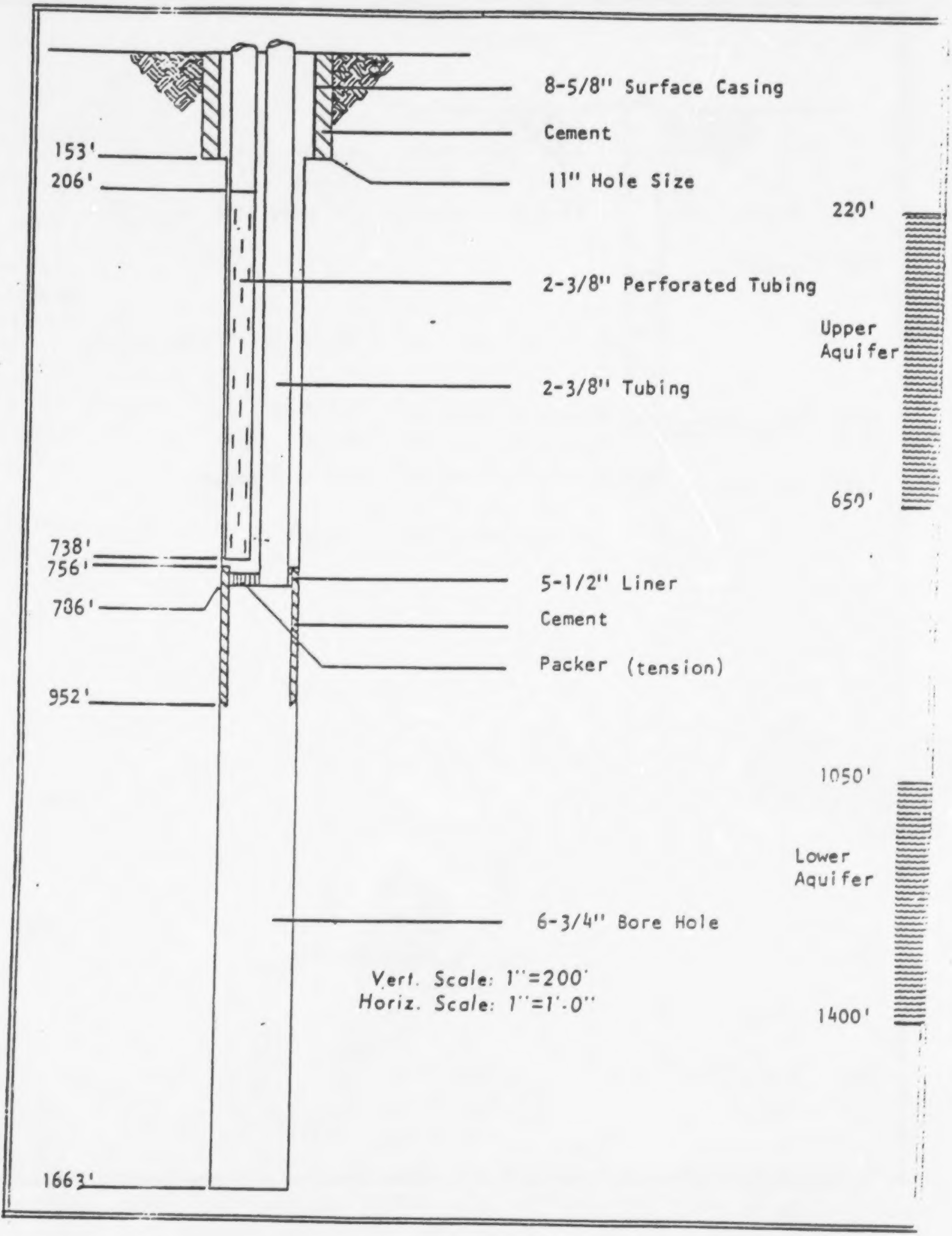


EXISTING WELL DETAIL, HOLE GS-2-3

RBOS Sept, 1977

174

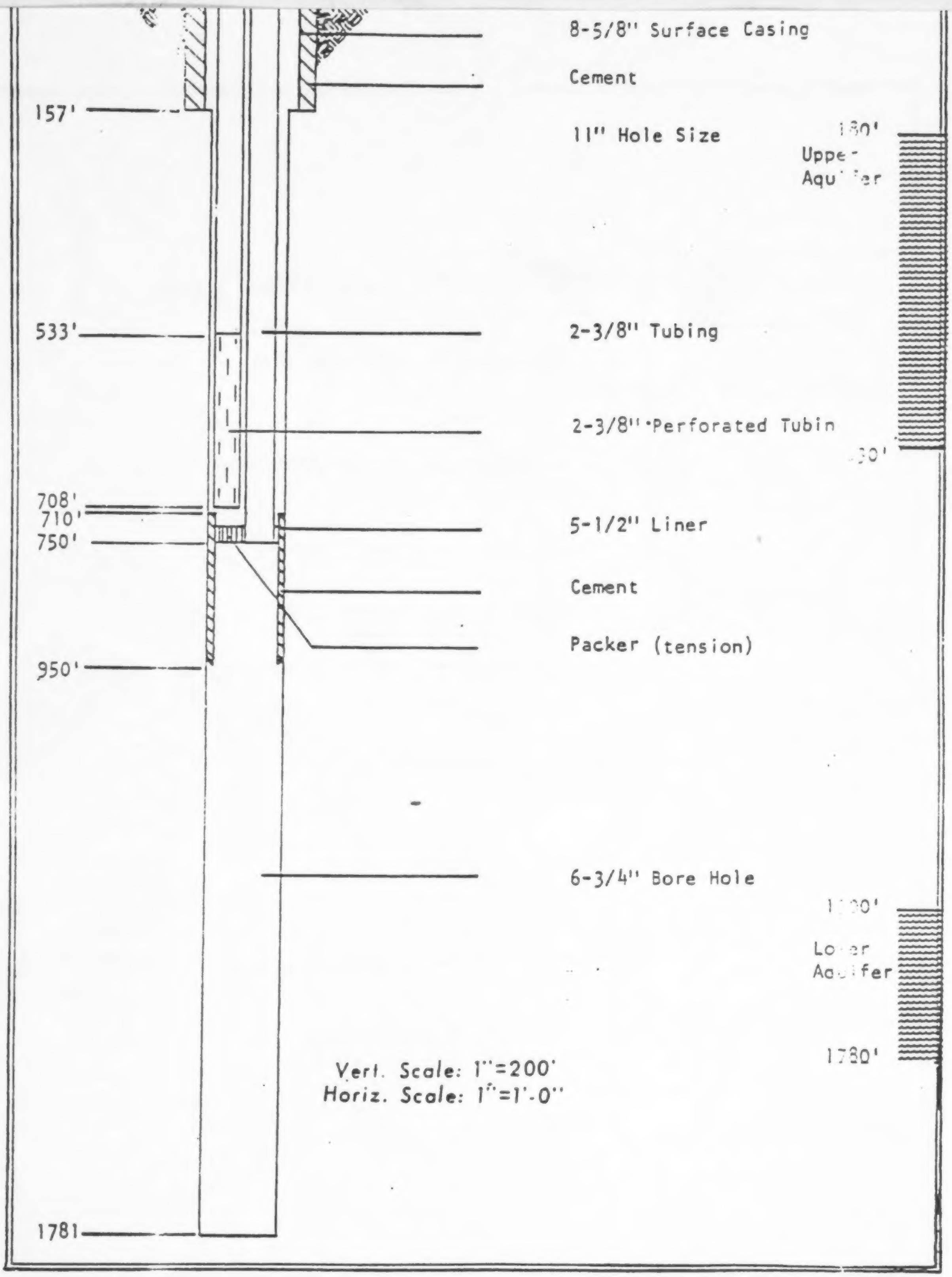
Figure 54



EXISTING WELL DETAIL, HOLE GS-4-5

175 RBOS Sept. 1977

Figure 55

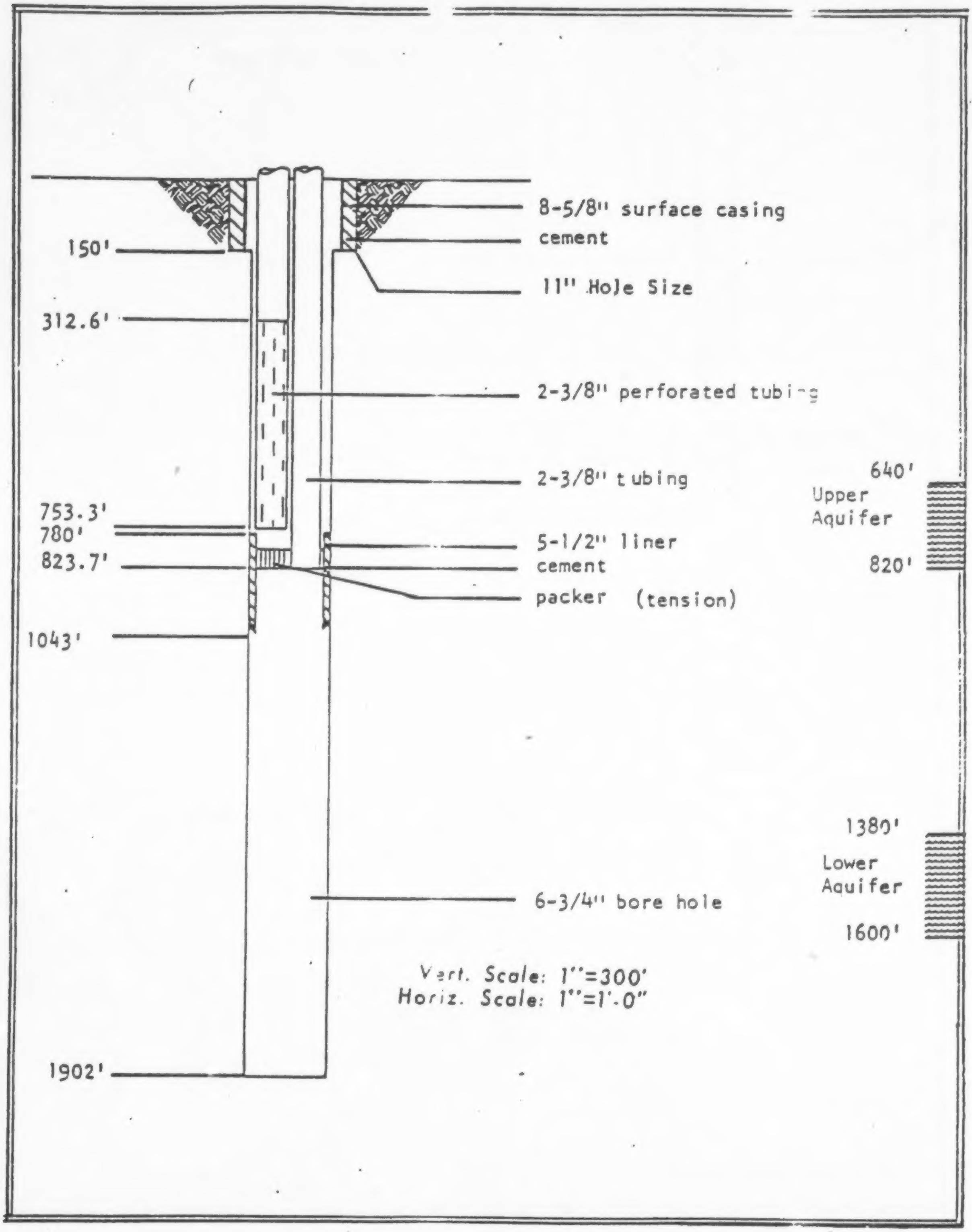


EXISTING WELL DETAIL, HOLE GS-6

RBOS Sept. 1977

176

Figure 56

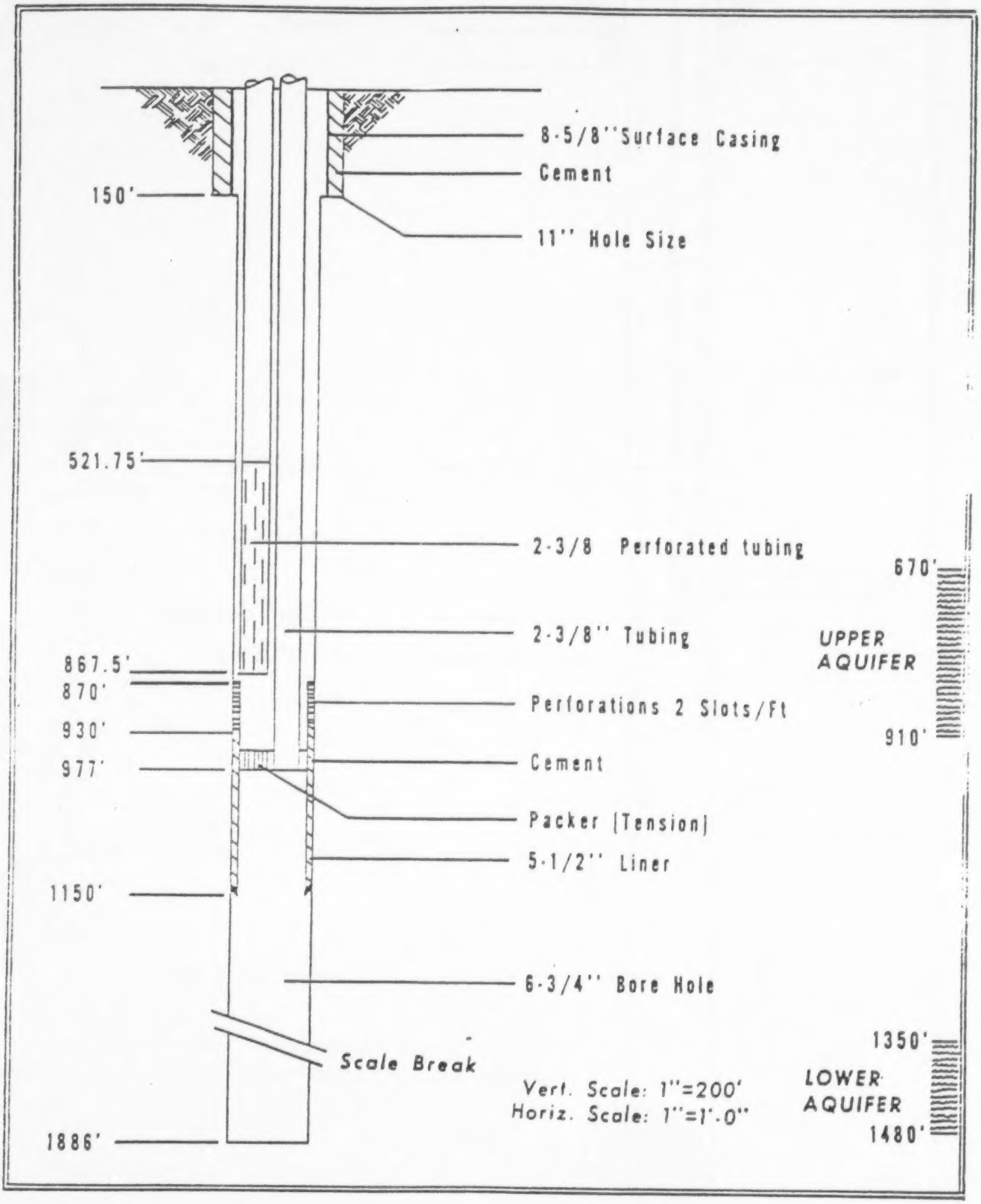


EXISTING WELL DETAIL, HOLE GS-10

RBOS Sept. 1977

177

Figure 57

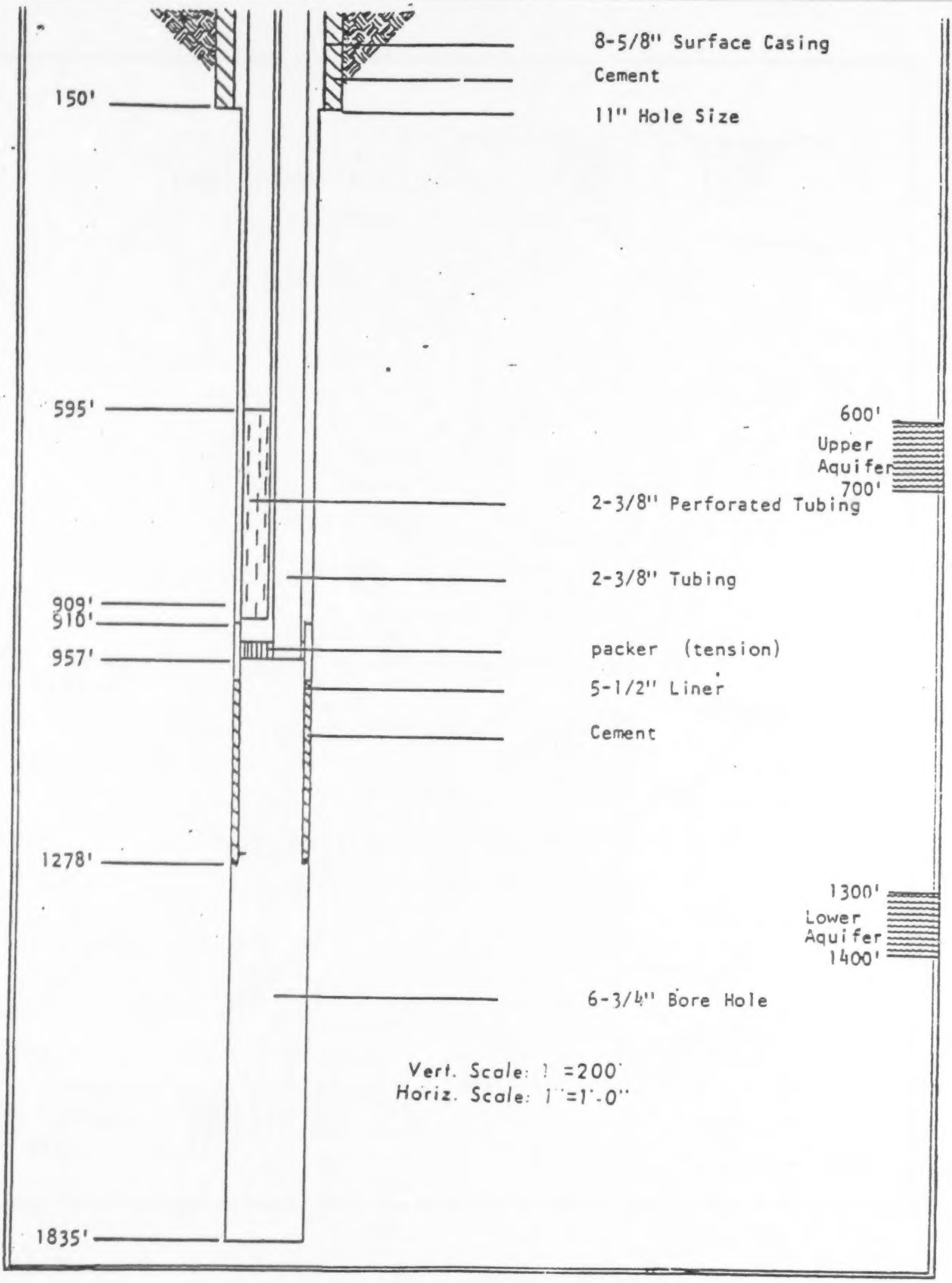


EXISTING WELL DETAIL, HOLE GS-11

RBOS Sept. 1977

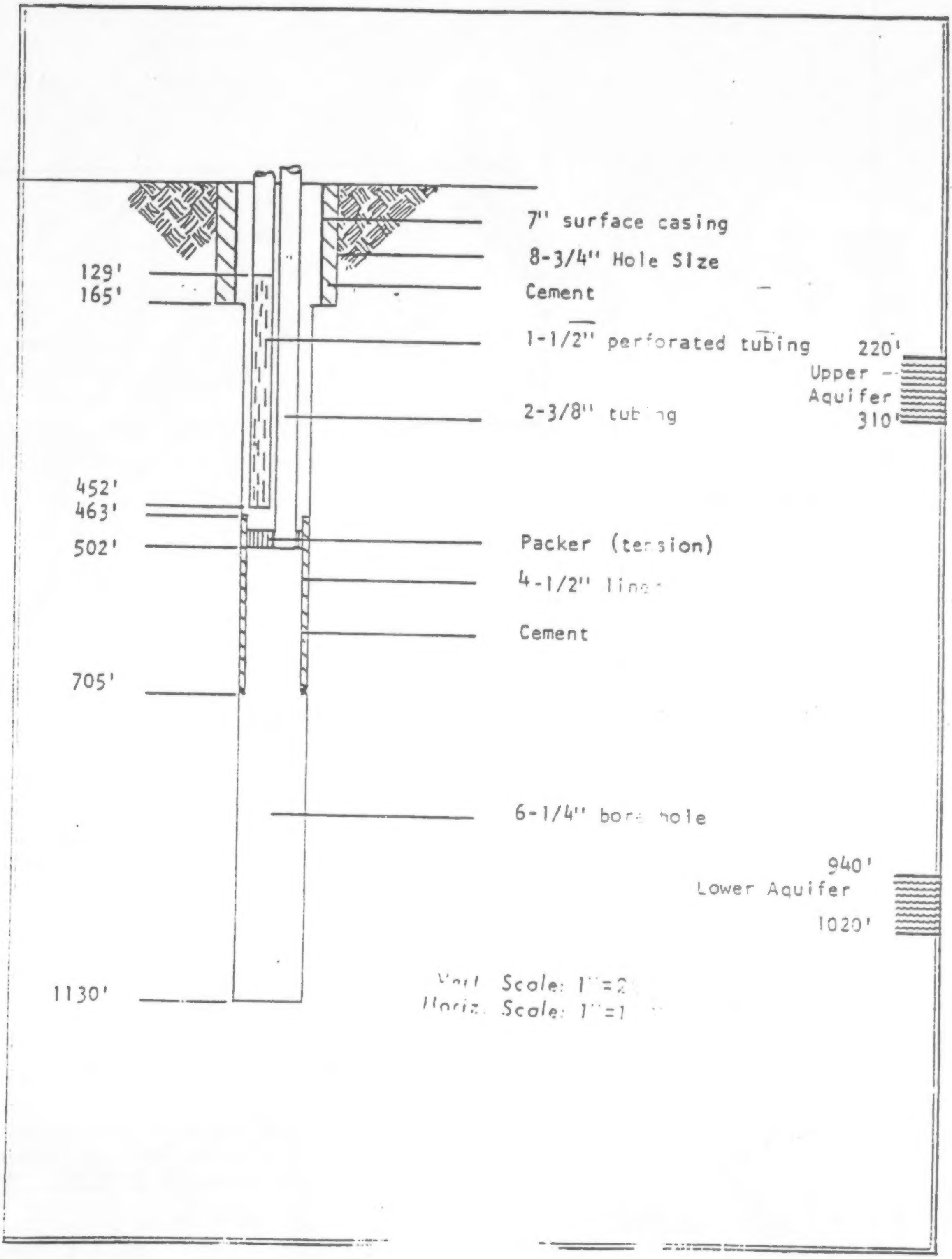
178

Figure 58



EXISTING WELL DETAIL, HOLE GS-15
RBOS Sept, 1977

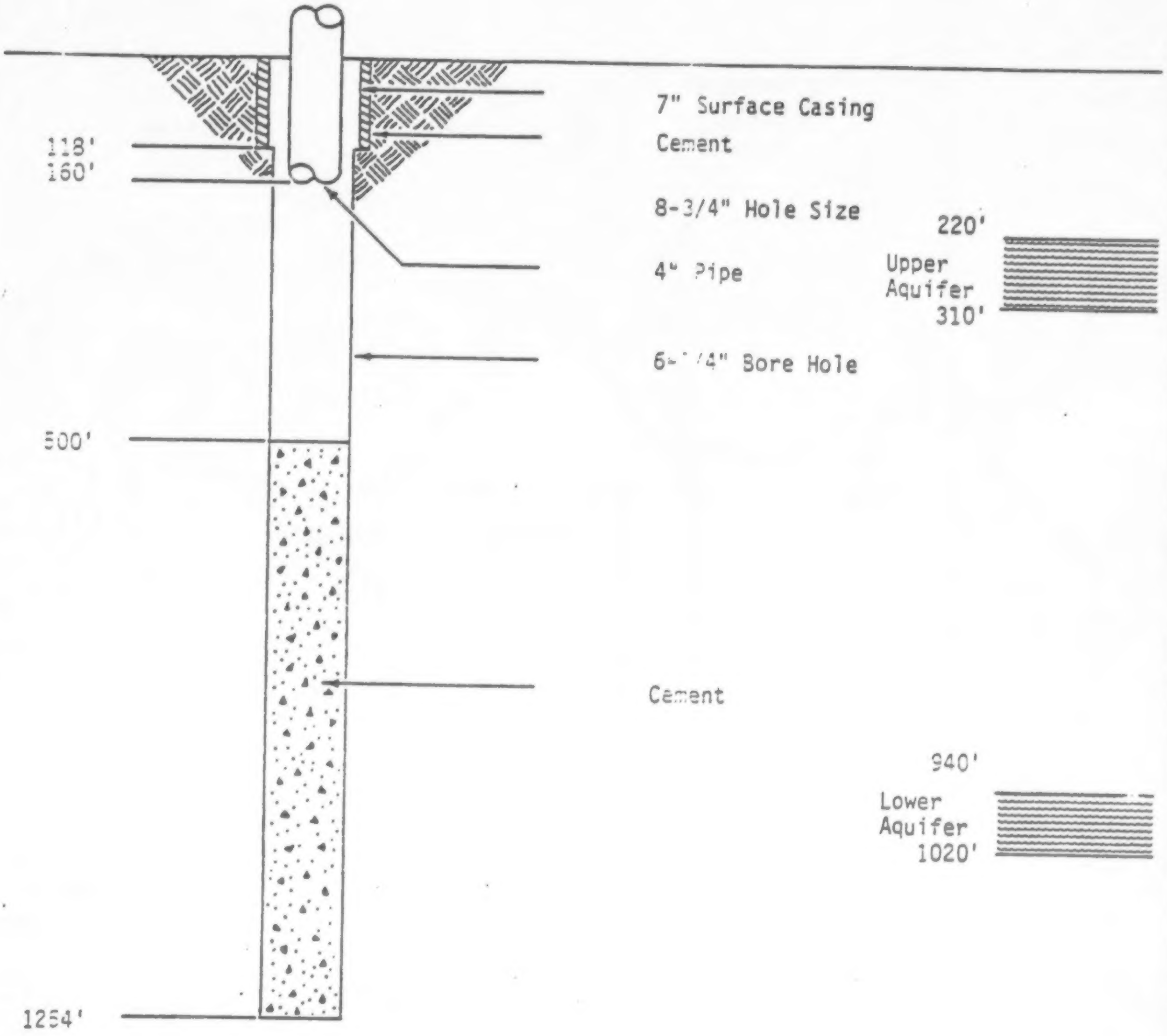
Figure 59



EXISTING WELL DETAIL, HOLE TO-2

RBOS Sept. 1977

Figure 60



Rio Blanco Oil Shale Company
RIO BLANCO COUNTY, COLORADO

Hole CE-701 Depth 1254'
March 9, 1979

DRAWN BY:
SCALE:
FIGURE:
DESIGN BY
DATE:
APPROVED BY:
DRAWING NO:

Revision 1.0
FILE:

Figure 61

HORIZONTAL SCALE: 1" = 1'-0"
VERTICAL SCALE: 1" = 200'

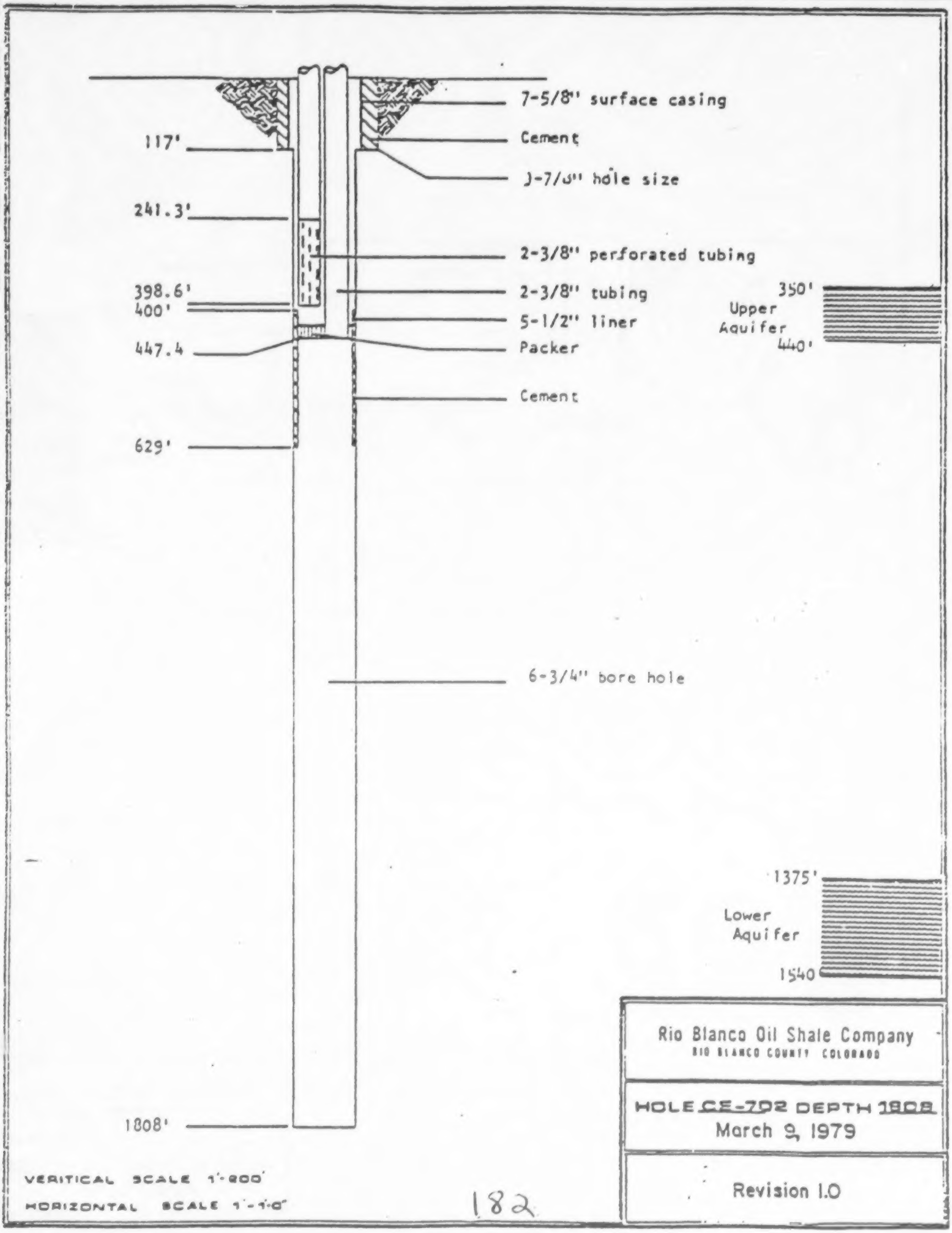
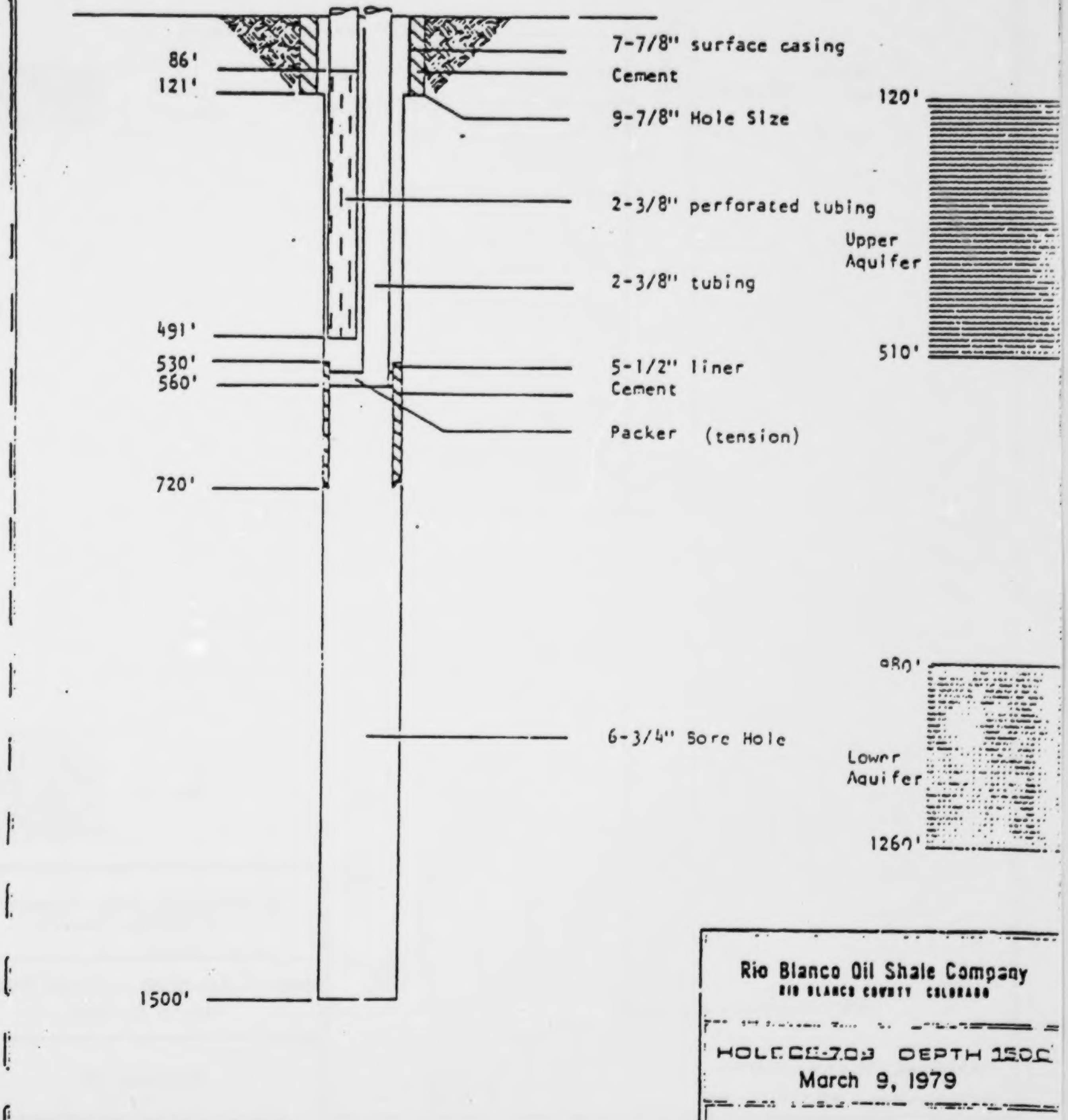

7-5/8" surface casing
Cement
9-7/8" hole size
2-3/8" perforated tubing
2-3/8" tubing
5-1/2" liner
Packer
Cement
6-3/4" bore hole
117'
241.3'
398.6'
400'
447.4
629'
1808'
350'
Upper Aquifer
440'
1375'
Lower Aquifer
1540
Rio Blanco Oil Shale Company
RIO BLANCO COUNTY COLORADO
HOLE CE-702 DEPTH 1808
March 9, 1979
Revision 1.0
VERITICAL SCALE 1"-200'
HORIZONTAL SCALE 1"-1'-0"

Figure 62



Rio Blanco Oil Shale Company
RIO BLANCO COUNTY COLORADO

HOLE CE-703 DEPTH 1500
March 9, 1979

Revision 1.0

VERITICAL SCALE 1"-200'
HORIZONTAL SCALE 1"-1-0"

Figure 63

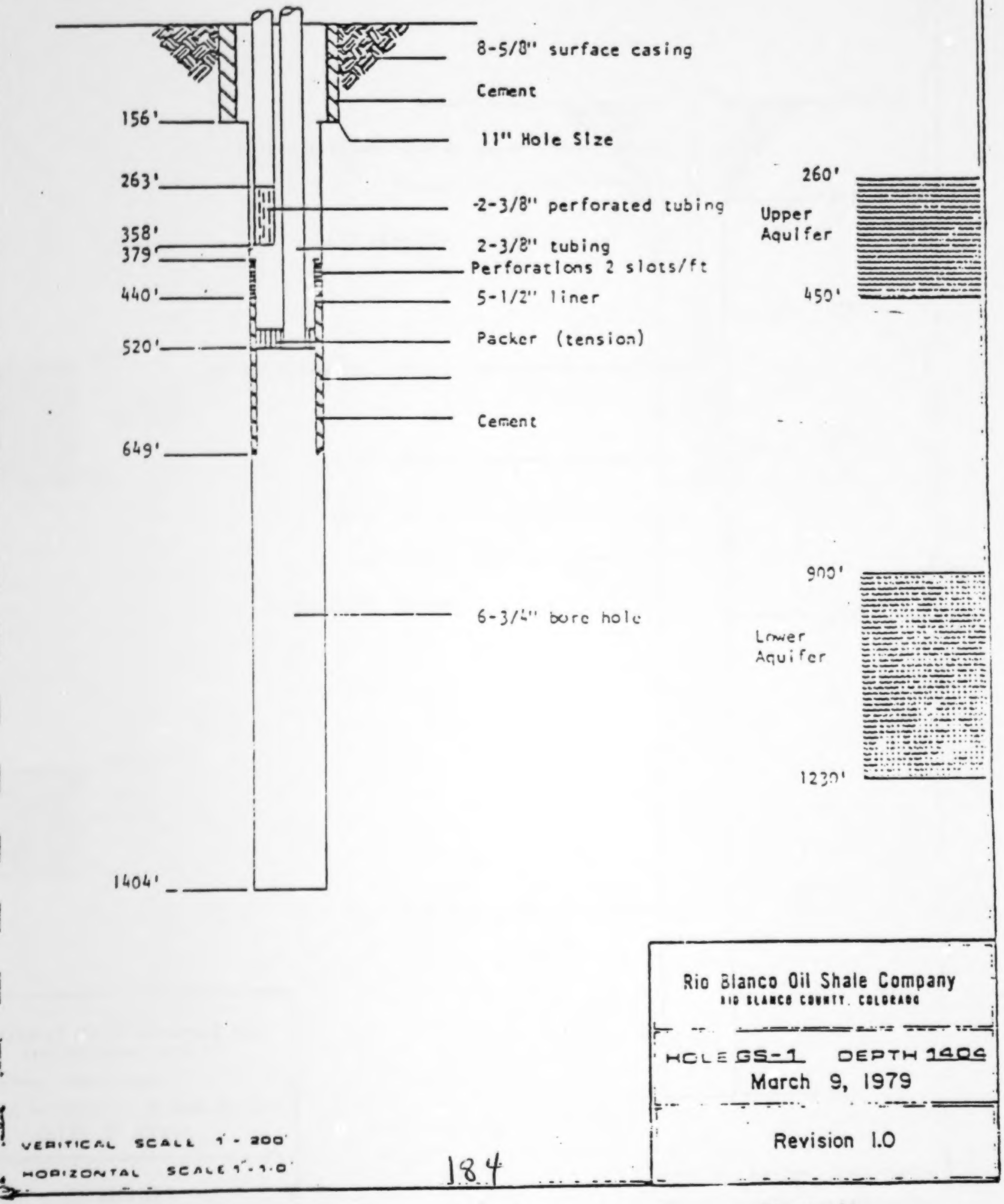
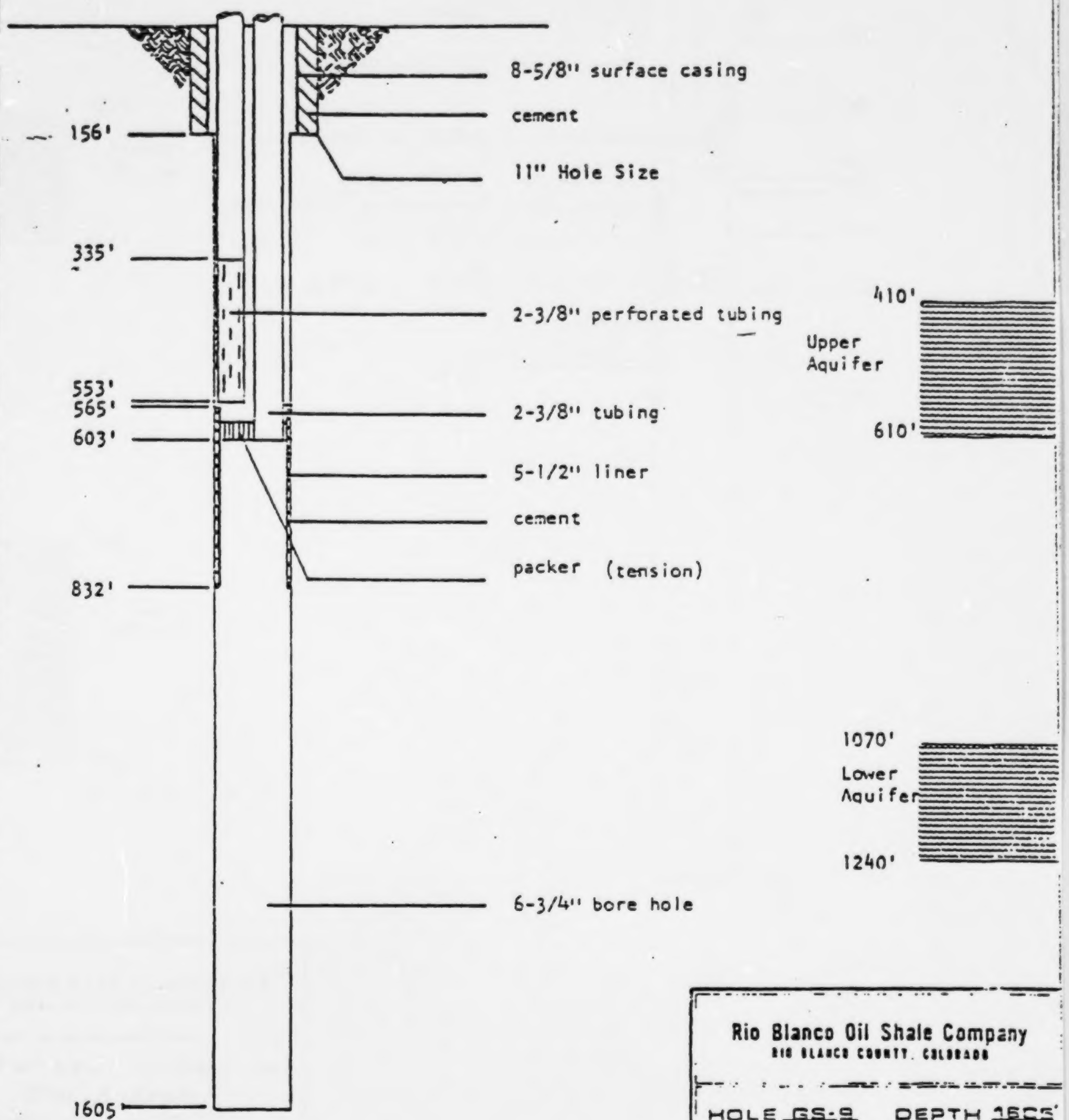

8-5/8" surface casing
Cement
11" Hole Size
156'
263'
2-3/8" perforated tubing
358'
379'
2-3/8" tubing
Perforations 2 slots/ft
440'
5-1/2" liner
520'
Packer (tension)
Cement
649'
6-3/4" bore hole
1404'
260'
Upper Aquifer
450'
900'
Lower Aquifer
1230'
Rio Blanco Oil Shale Company
RIO BLANCO COUNTY, COLORADO
HOLE GS-1 DEPTH 1404
March 9, 1979
Revision 1.0
VERITICAL SCALE 1" - 200'
HORIZONTAL SCALE 1" - 1.0'

Figure 64



VERITICAL SCALE 1"-200'
HORIZONTAL SCALE 1"-1'-0"

Rio Blanco Oil Shale Company
RIO BLANCO COUNTY, COLORADO

HOLE GS-9 DEPTH 1605'
March 9, 1979

Revision 1.0

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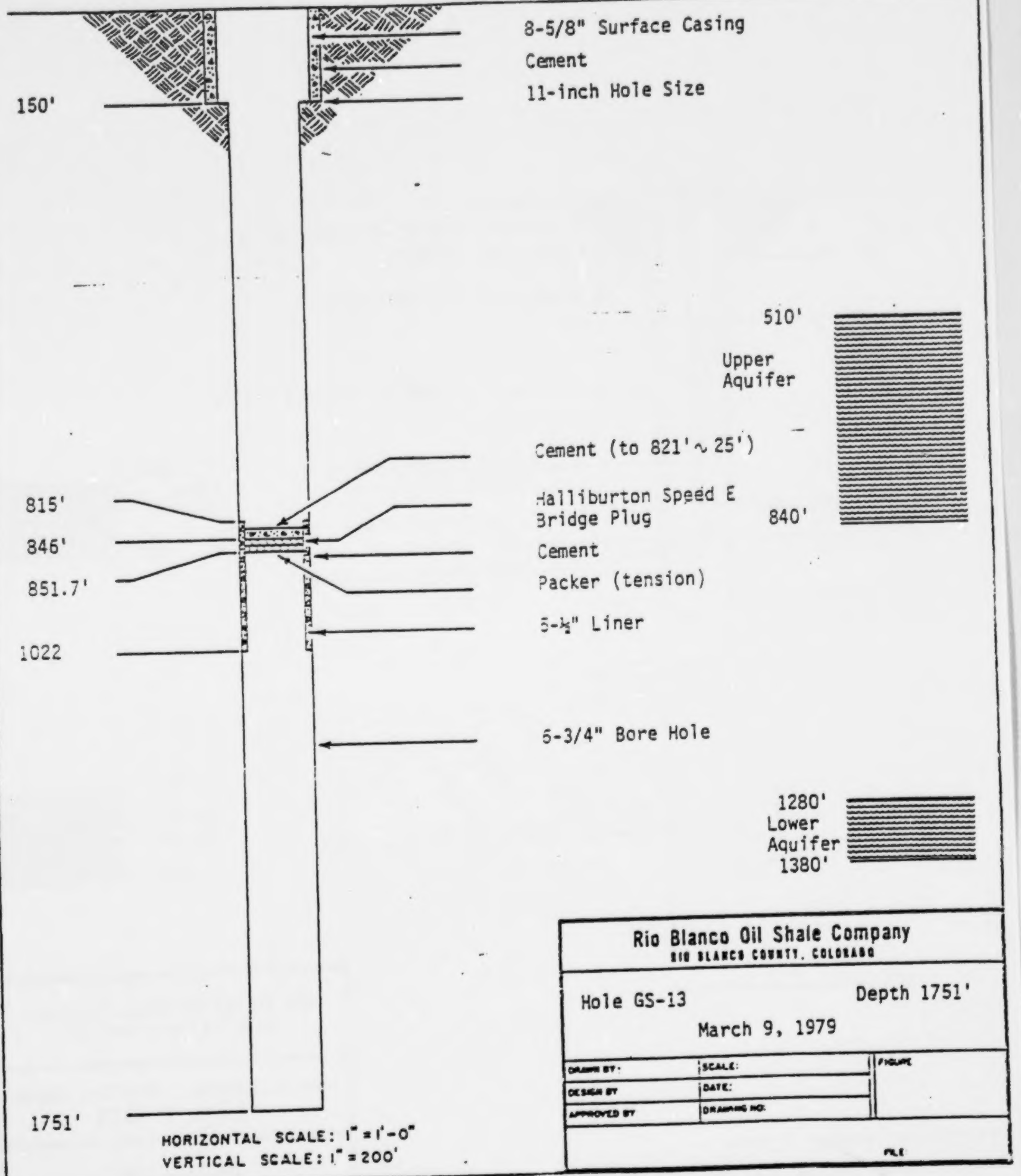
Figure 65



Rio Blanco Oil Shale Company
RIO BLANCO COUNTY, COLORADO

Hole GS-13 Depth 1751'

March 9, 1979

186

Figure 66

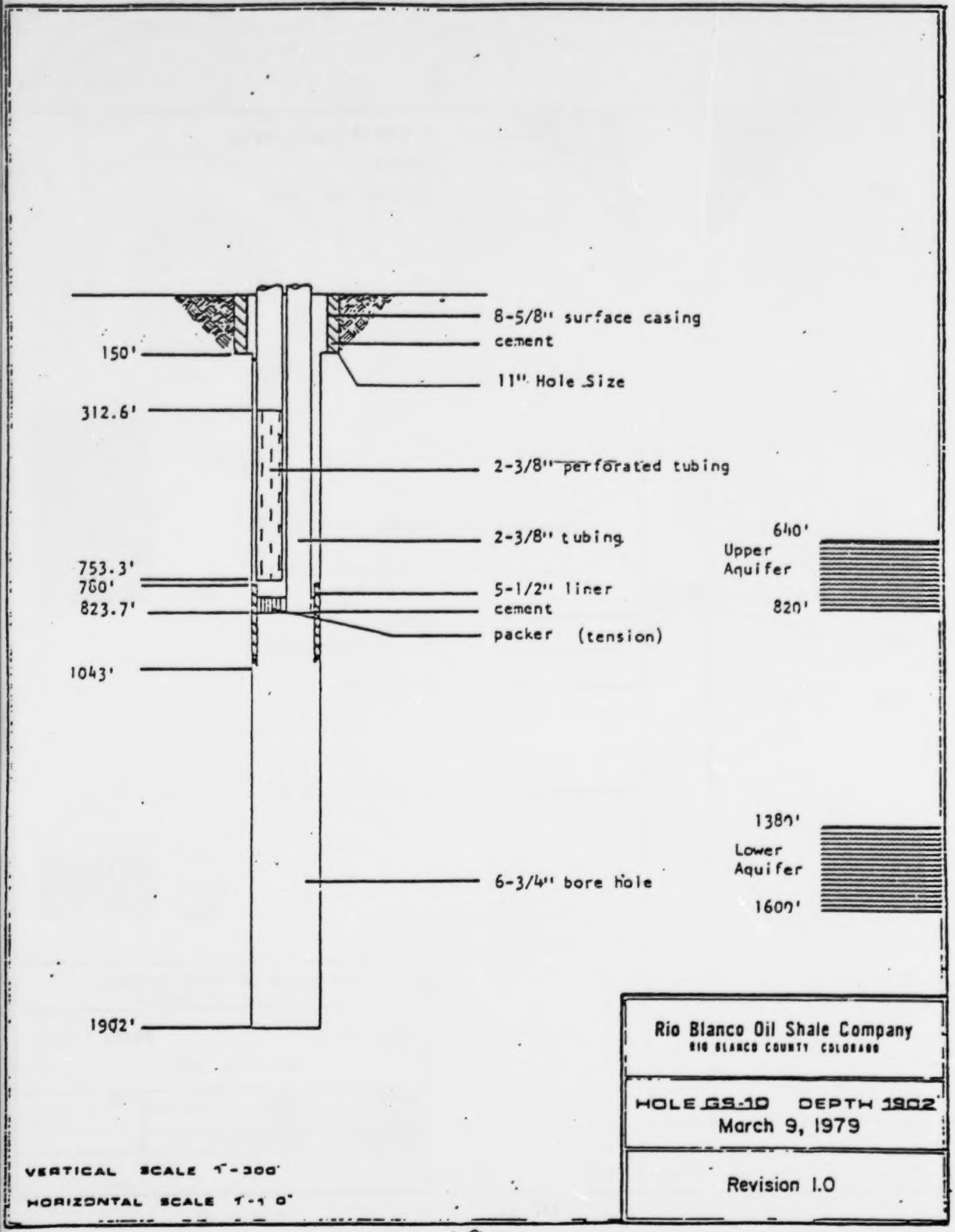

8-5/8" surface casing
cement
150'
11" Hole Size
312.6'
2-3/8" perforated tubing
2-3/8" tubing
753.3'
760'
823.7'
5-1/2" liner
cement
packer (tension)
1043'
640'
Upper Aquifer
820'
1380'
Lower Aquifer
1600'
6-3/4" bore hole
1902'
Rio Blanco Oil Shale Company
RIO BLANCO COUNTY COLORADO
HOLE GS-10 DEPTH 1902'
March 9, 1979
Revision 1.0
VERTICAL SCALE 1"-300'
HORIZONTAL SCALE 1"-1 0"

Figure 67

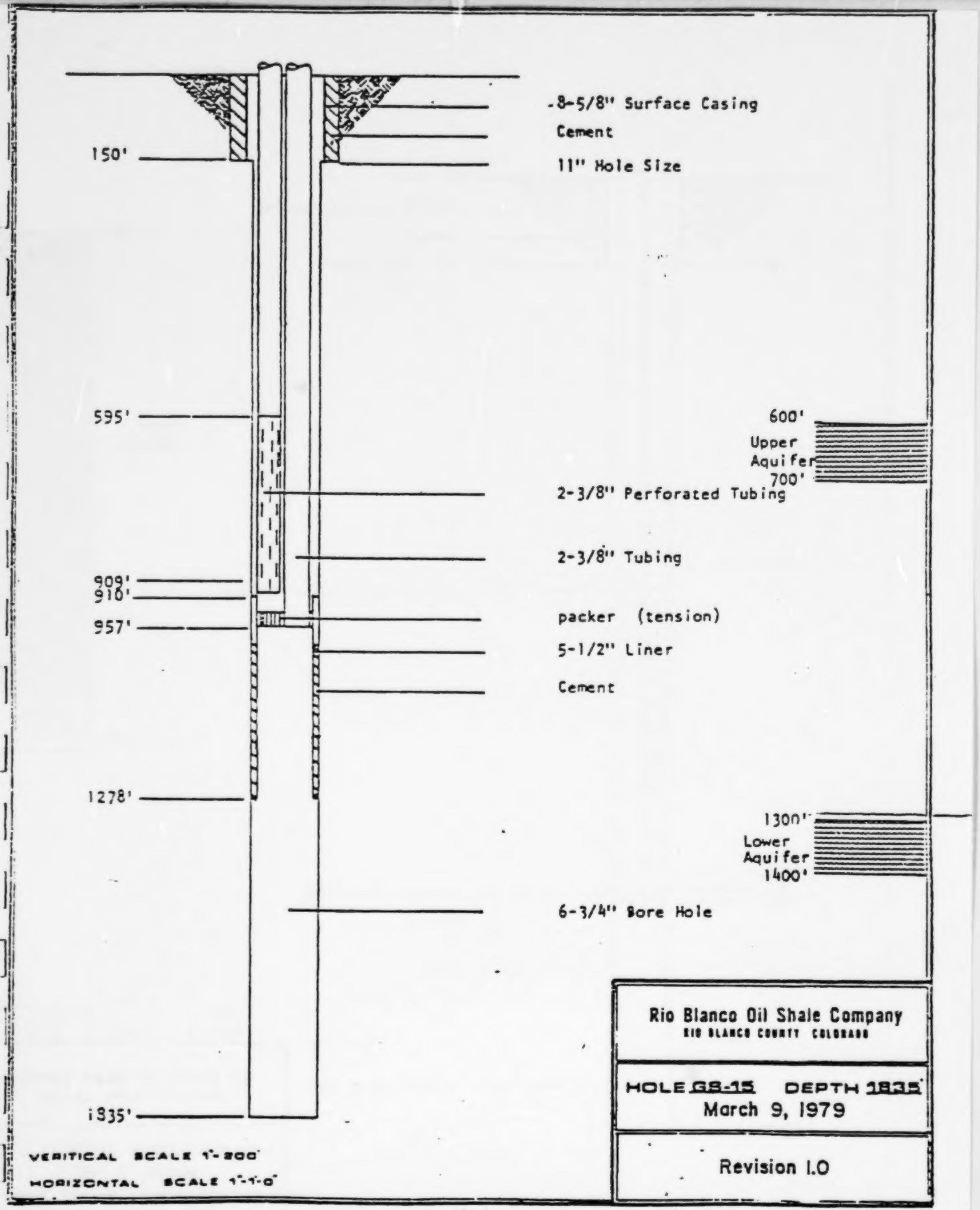
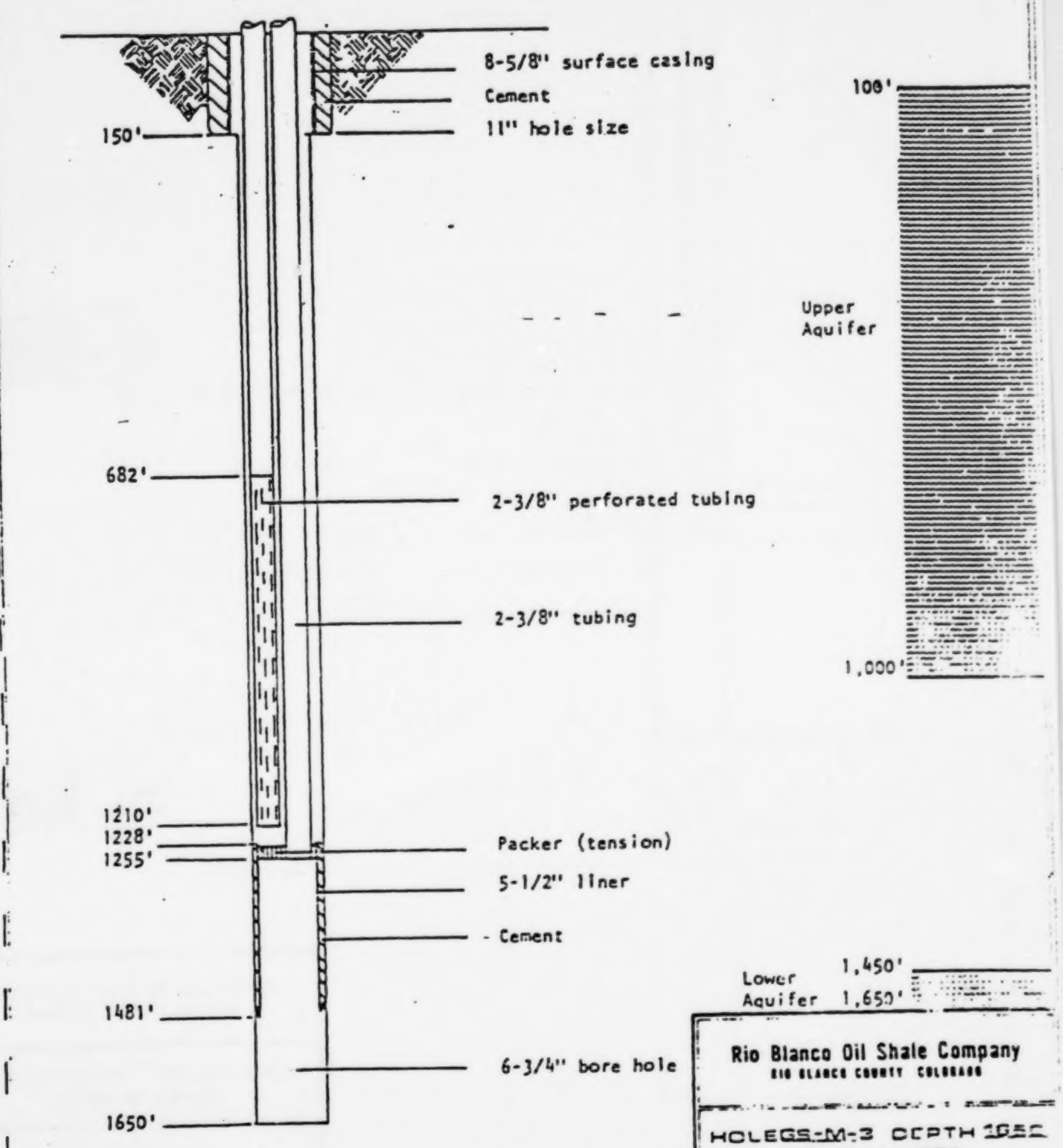

-8-5/8" Surface Casing
Cement
150'
11" Hole Size
595'
600'
Upper Aquifer
700'
2-3/8" Perforated Tubing
2-3/8" Tubing
909'
910'
packer (tension)
957'
5-1/2" Liner
Cement
1278'
1300'
Lower Aquifer
1400'
6-3/4" Bore Hole
1935'
VERITICAL SCALE 1"-200'
HORIZONTAL SCALE 1"-1'-0"
Rio Blanco Oil Shale Company
RIO BLANCO COUNTY COLORADO
HOLE GS-15 DEPTH 1835'
March 9, 1979
Revision 1.0

Figure 68



Rio Blanco Oil Shale Company
RIO BLANCO COUNTY COLORADO

HOLE GS-M-3 DEPTH 1650
March 9, 1979

Revision 1.0

VERITICAL SCALE 1"= 200'
HORIZONTAL SCALE 1"= 1'-0"

Figure 69

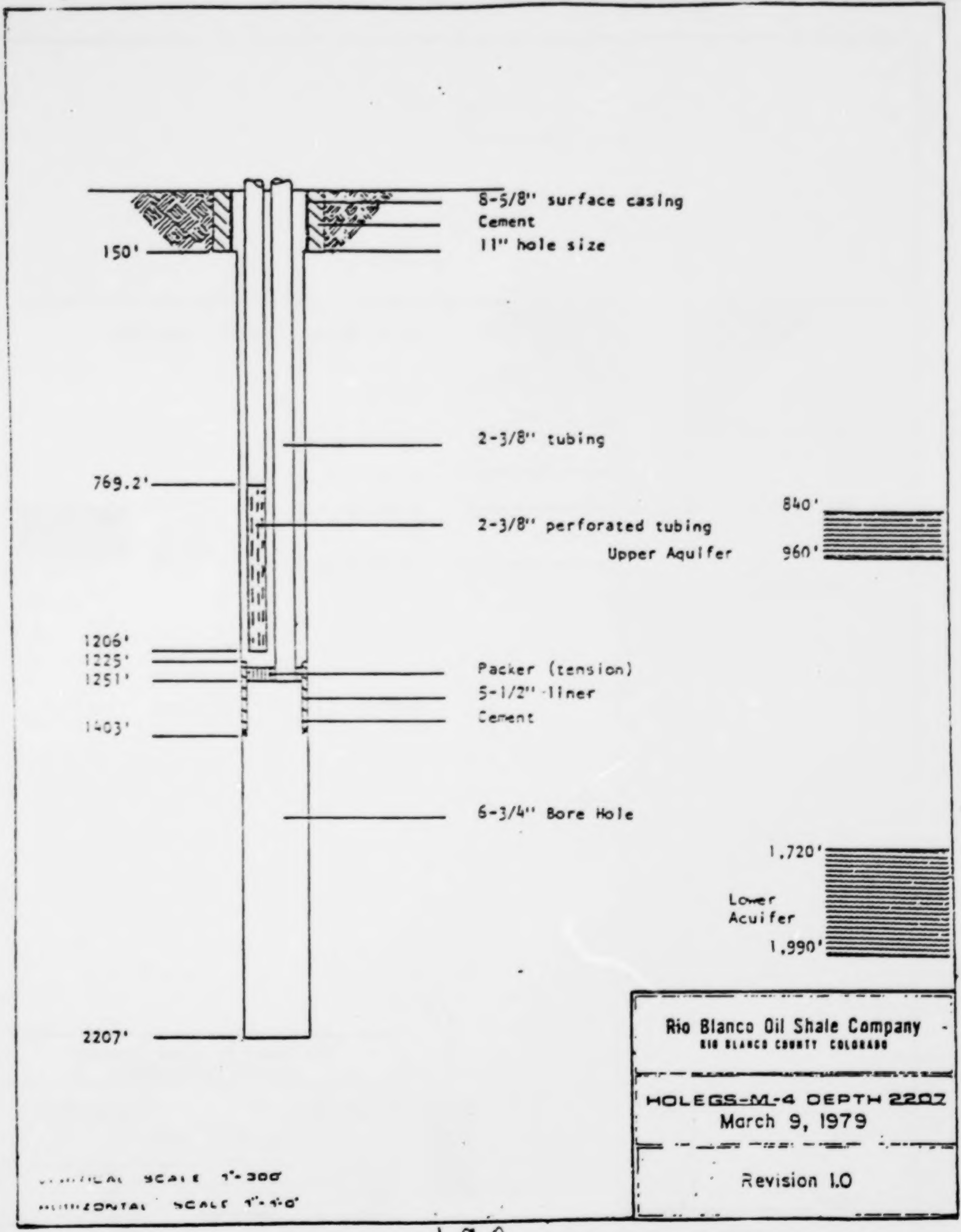
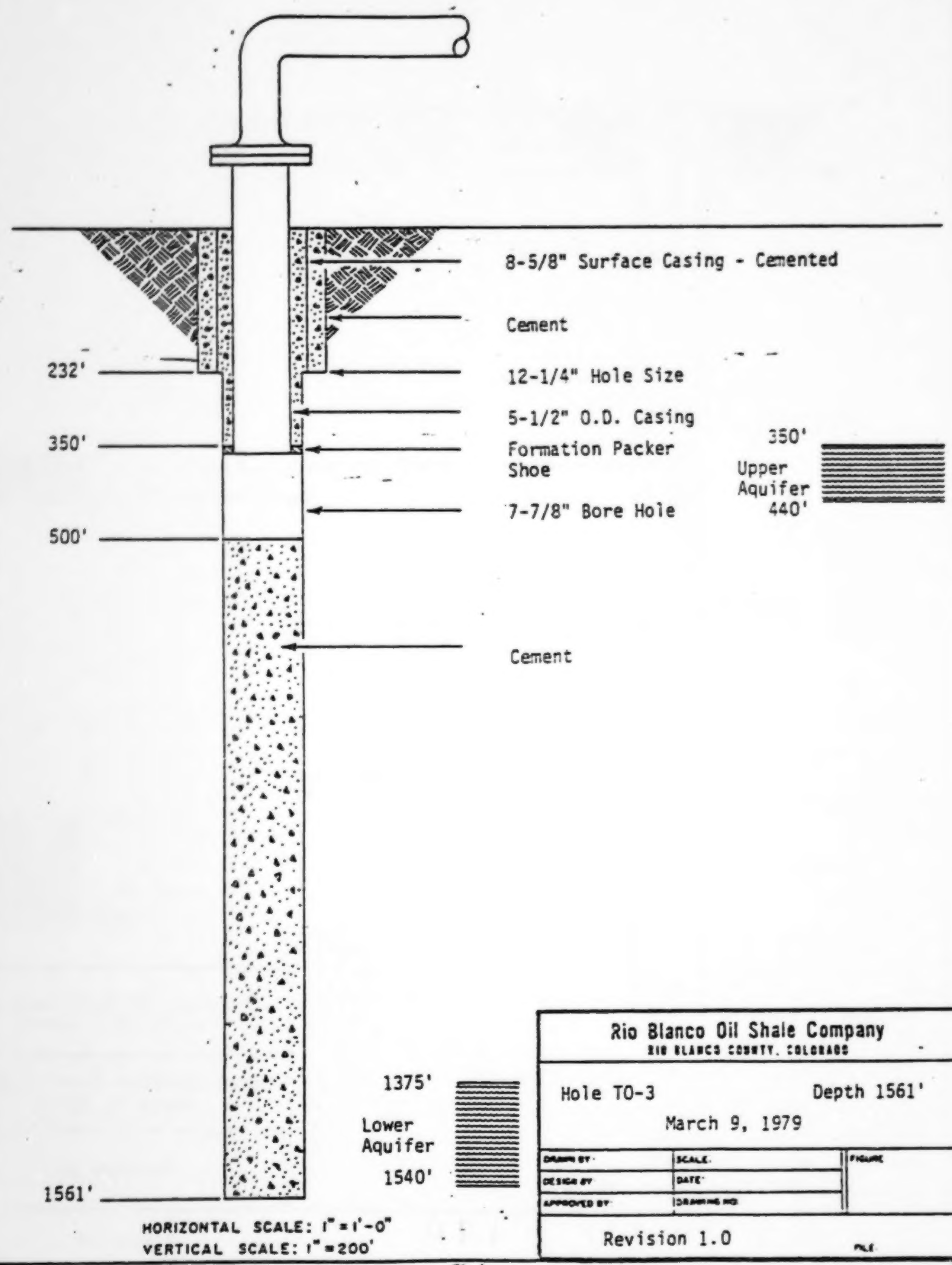

8-5/8" surface casing
Cement
11" hole size
150'
2-3/8" tubing
769.2'
2-3/8" perforated tubing
840'
Upper Aquifer
960'
1206'
1225'
1251'
1403'
Packer (tension)
5-1/2" liner
Cement
6-3/4" Bore Hole
1,720'
Lower
Acuifer
1,990'
2207'
Rio Blanco Oil Shale Company
RIO BLANCO COUNTY COLORADO
HOLE GS-M-4 DEPTH 2207
March 9, 1979
Revision 1.0
VERTICAL SCALE 1"=300'
HORIZONTAL SCALE 1"=1'0"

Figure 70



Rio Blanco Oil Shale Company
RIO BLANCO COUNTY, COLORADO

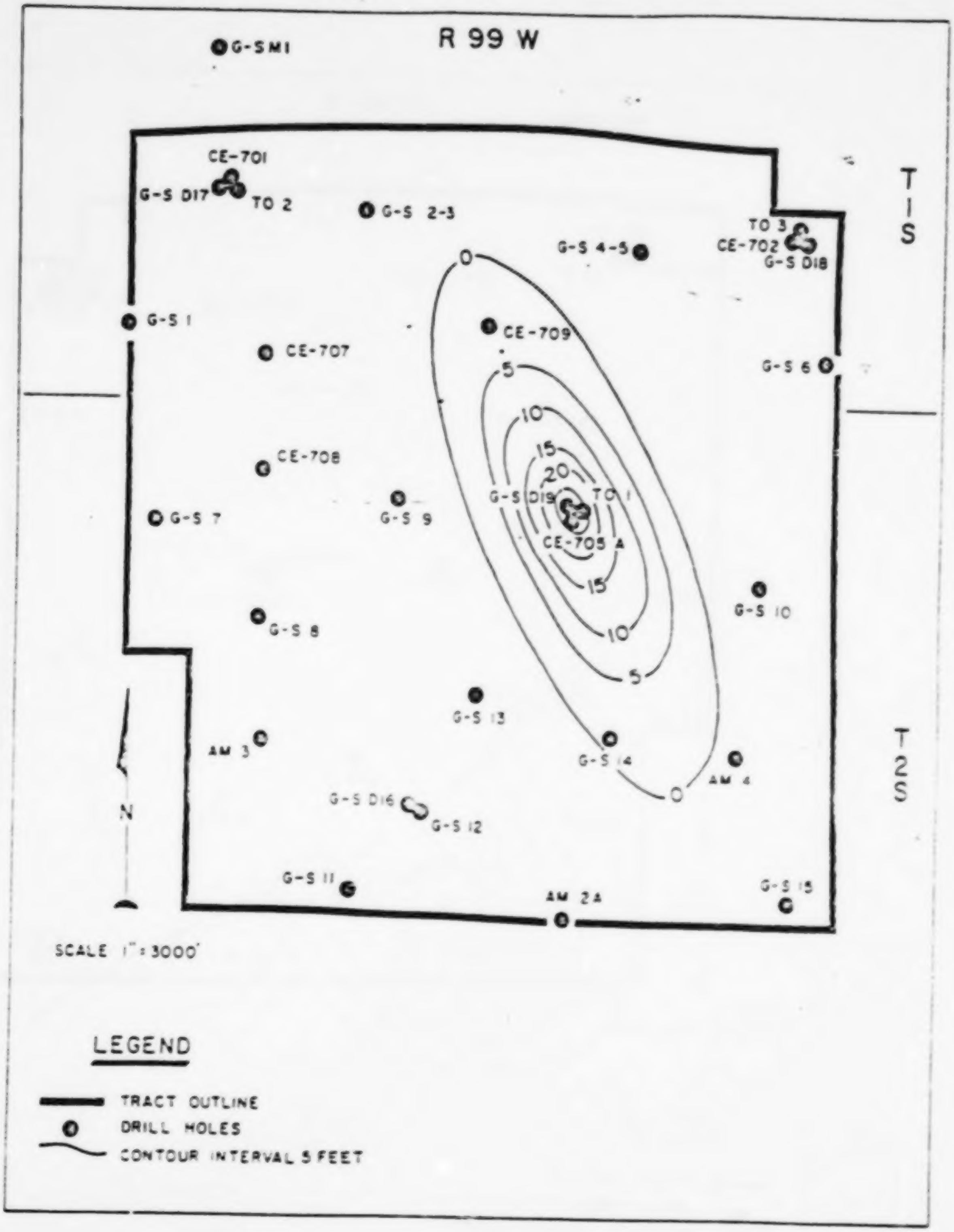
Hole TO-3 Depth 1561'
March 9, 1979

DRAWN BY	SCALE	FIGURE
DESIGN BY	DATE	
APPROVED BY	DRAWING NO.	

Revision 1.0 FILE

191

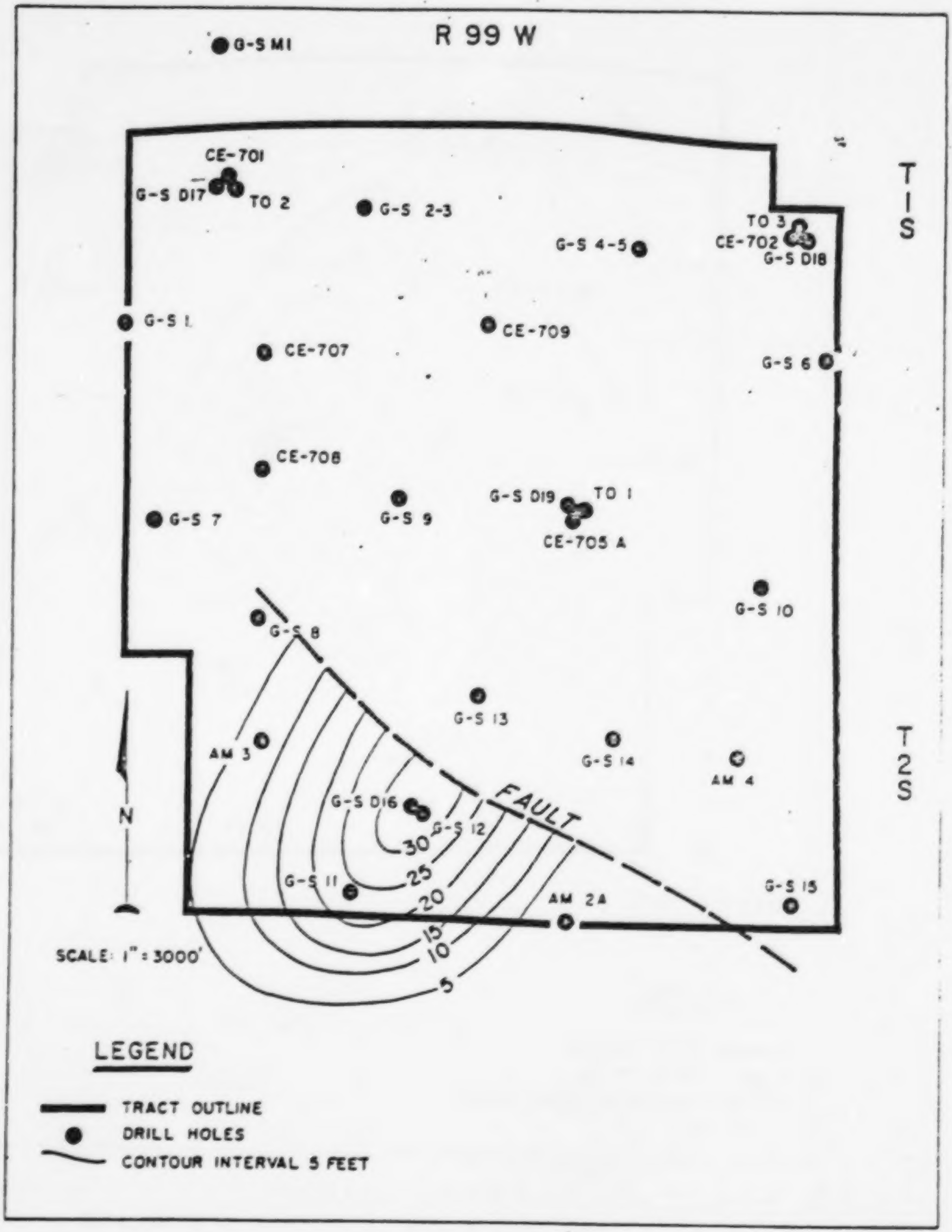
Figure 71



UPPER AQUIFER PUMPING TEST CONE OF DEPRESSION

(R.B.O.S.C. May 1977)

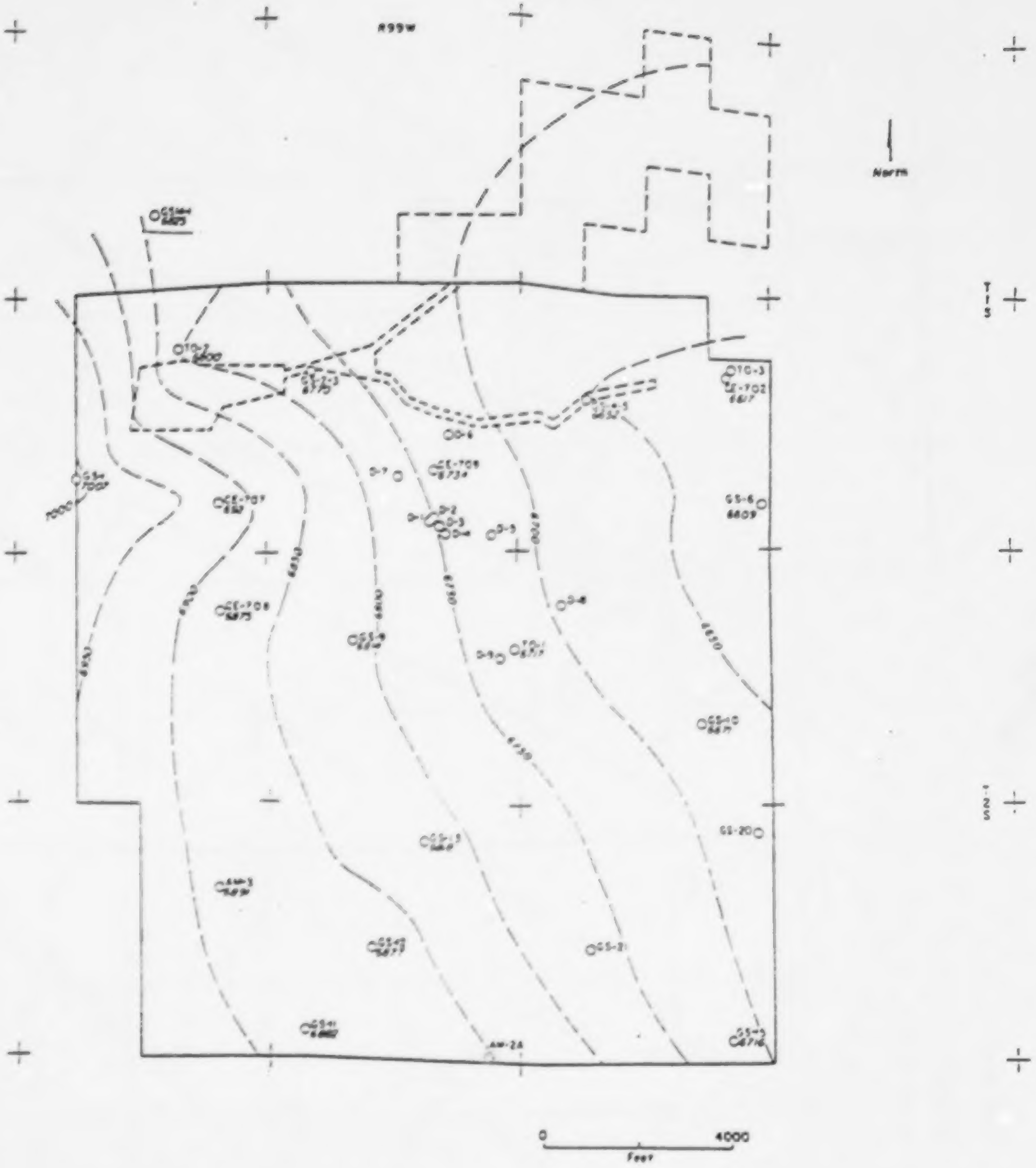
Figure 72



UPPER AQUIFER PUMPING TEXT DRAWDOWN, G-S 12
AT APPROXIMATELY 13,000 MINUTES

(R.B.O.S.C. May 1977)

Figure 73



Upper Aquifer Piezometric Levels - May 15, 1975

(R.B.O.S.C. Feb. 1981)

194

Figure 74

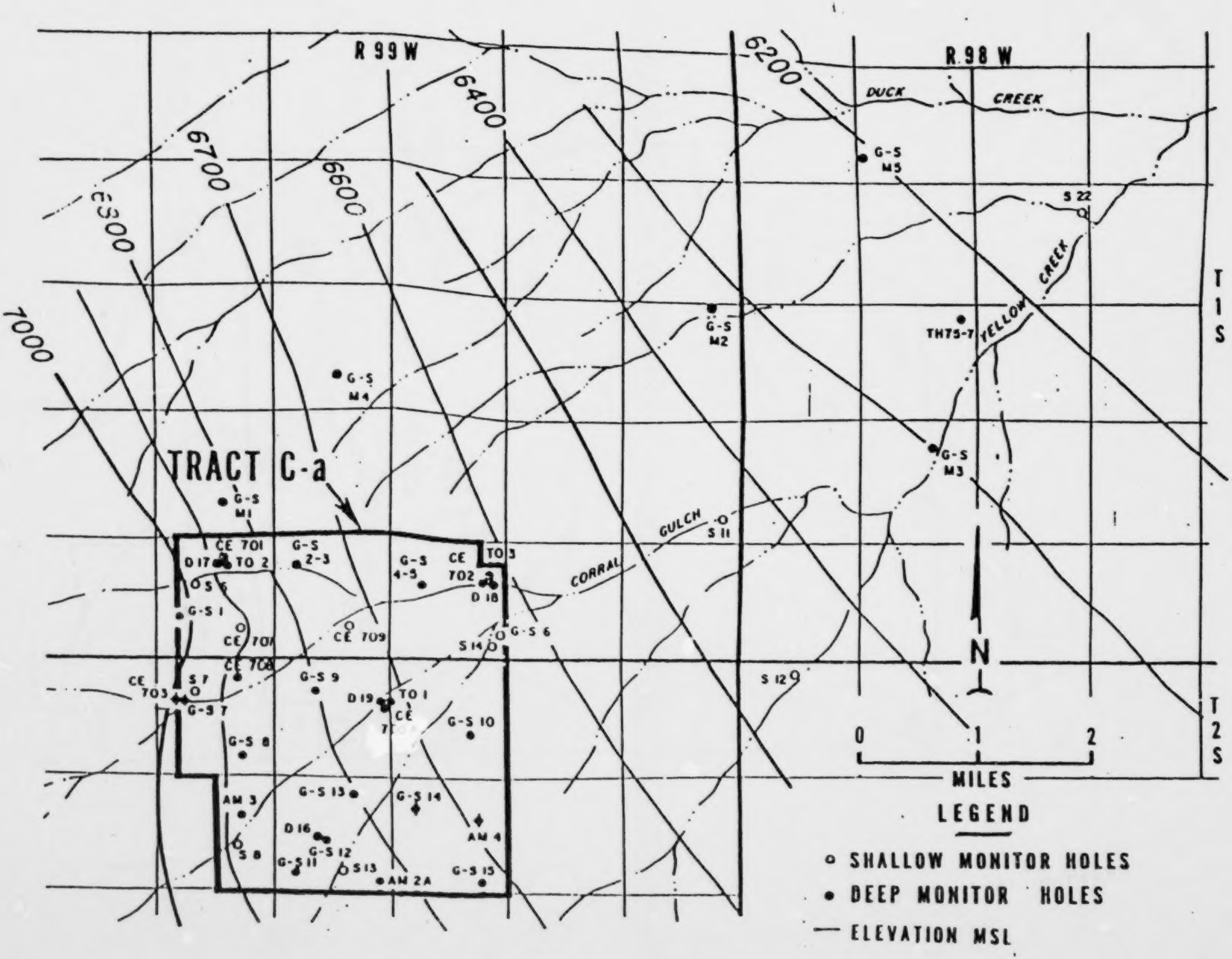
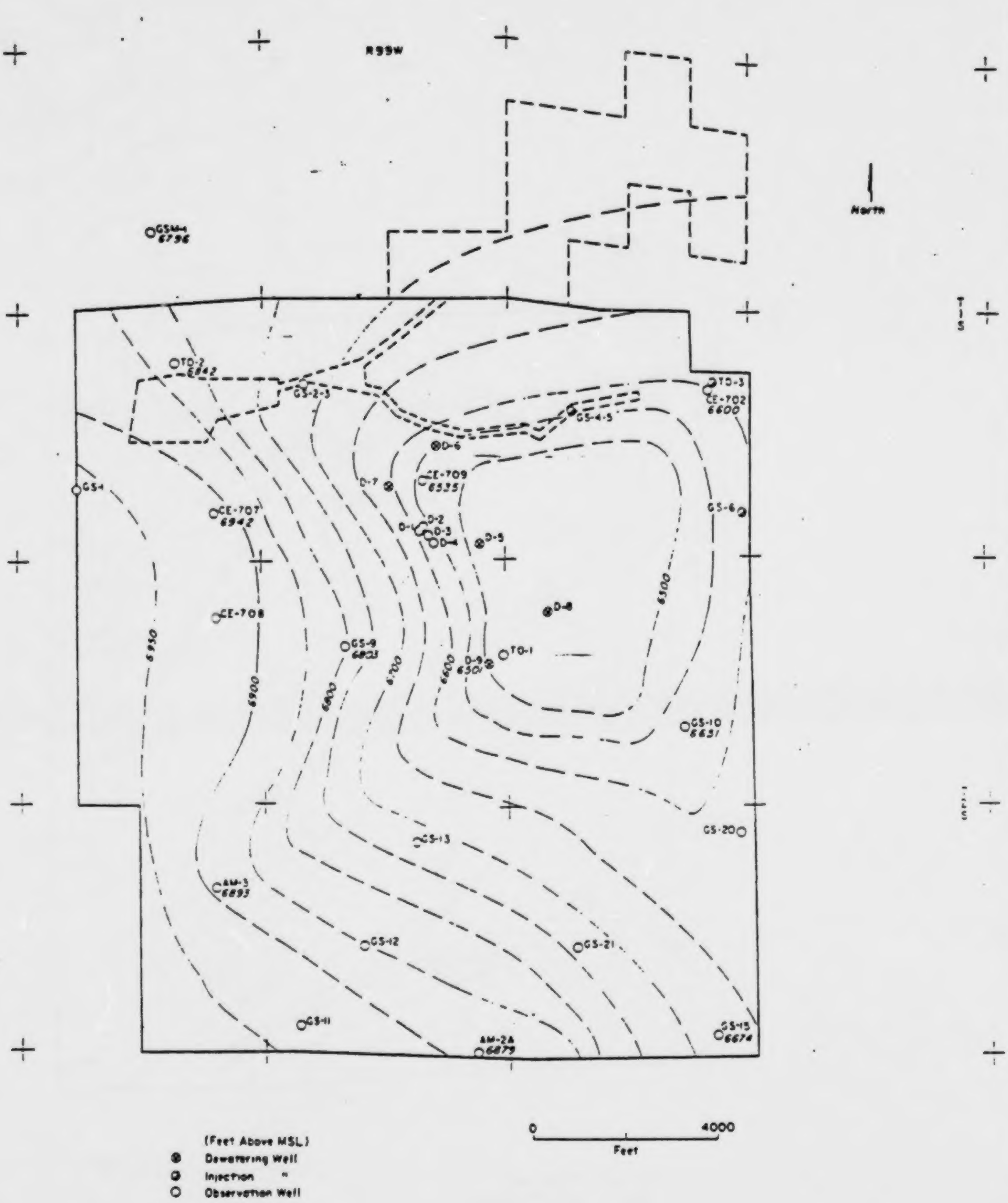


Figure 75

UPPER AQUIFER PIEZOMETRIC SURFACE, FALL 1976

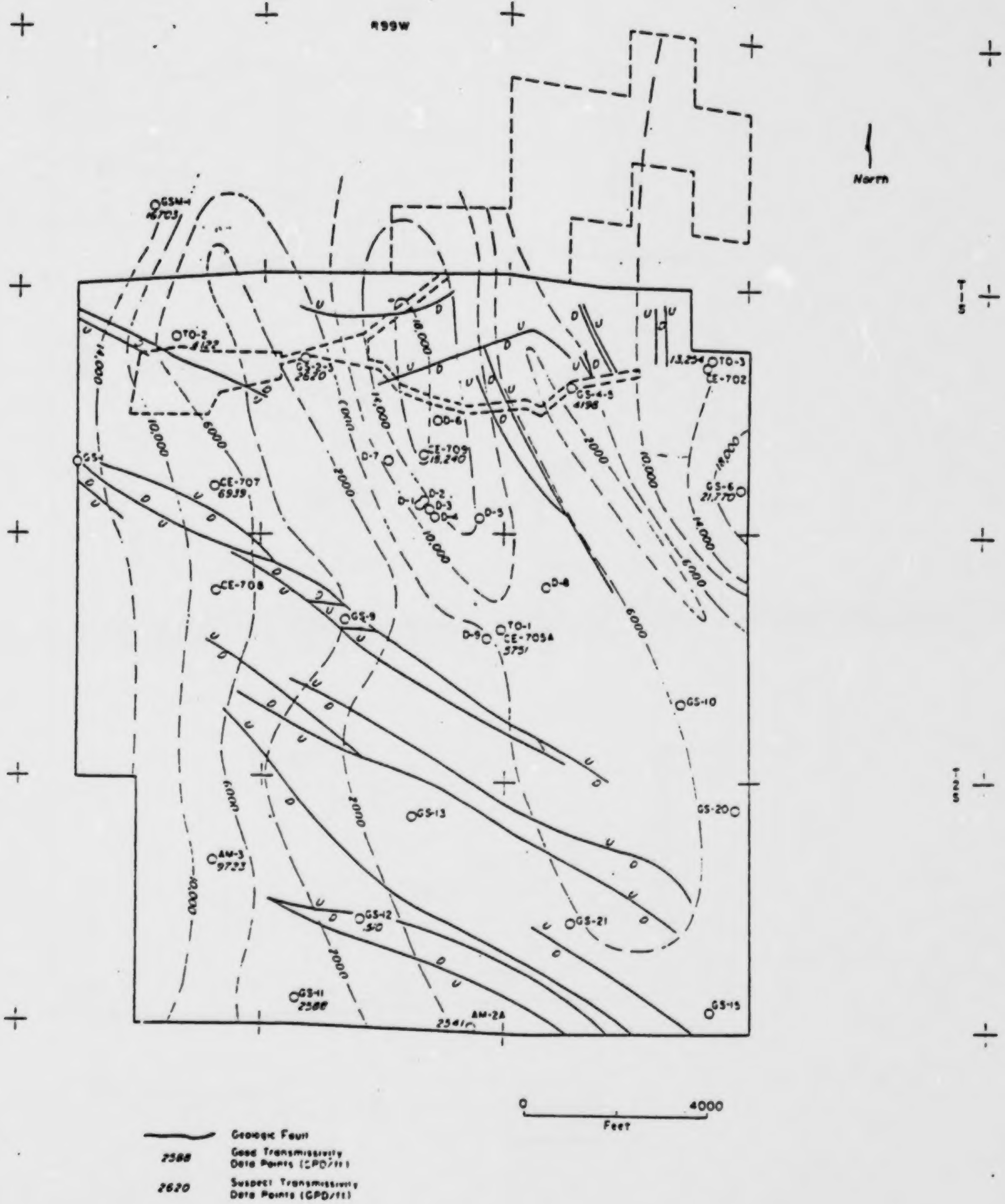
(R.B.O.S.C., Sept. 1977)



Upper Aquifer Piezometric Levels - November 30, 1979

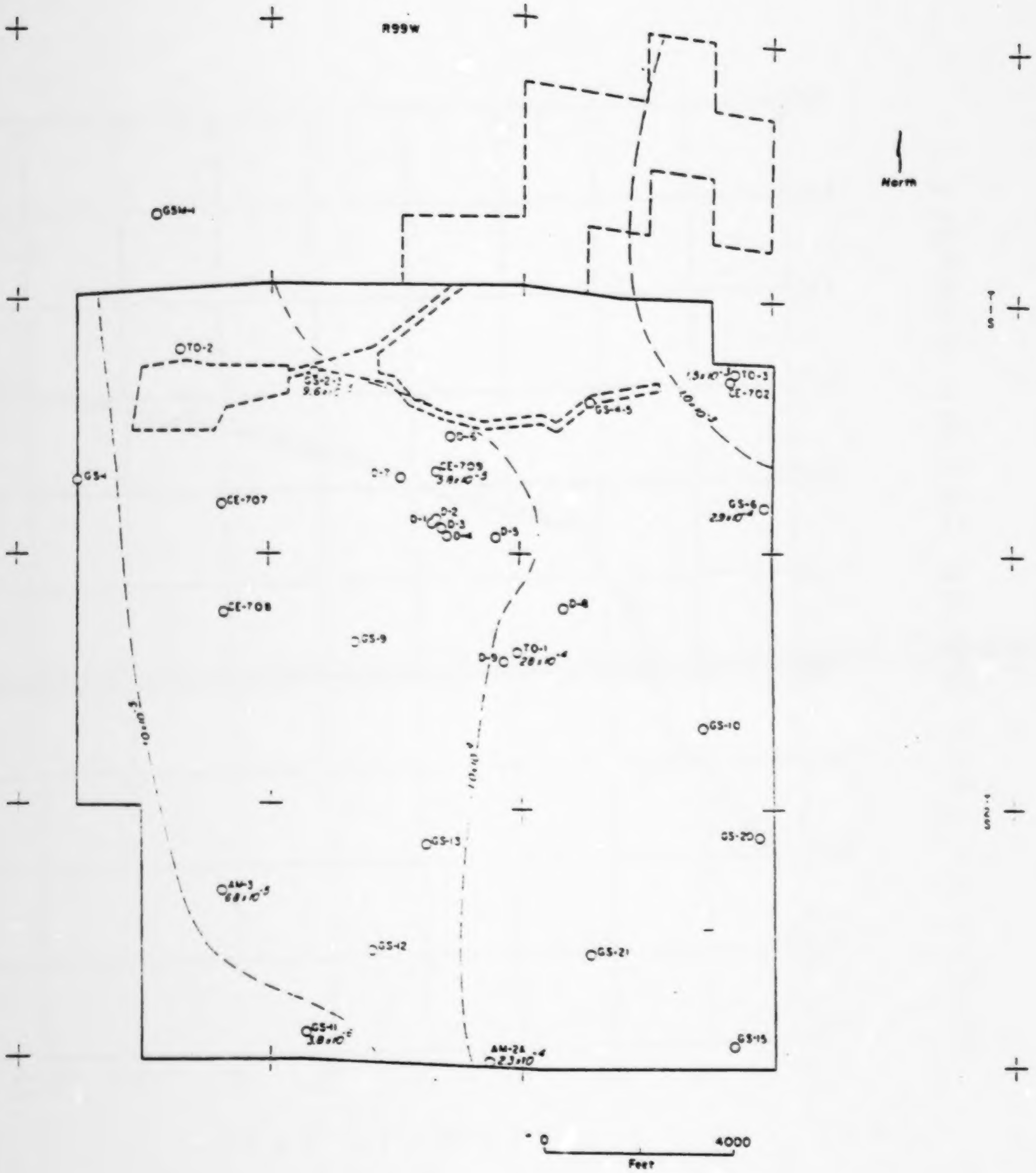
(R.B.O.S.C. Feb. 1981)

Figure 76



Upper Aquifer Transmissivity (GPD/ft.)
(R.B.O.S.C. Feb. 1981)

Figure 77

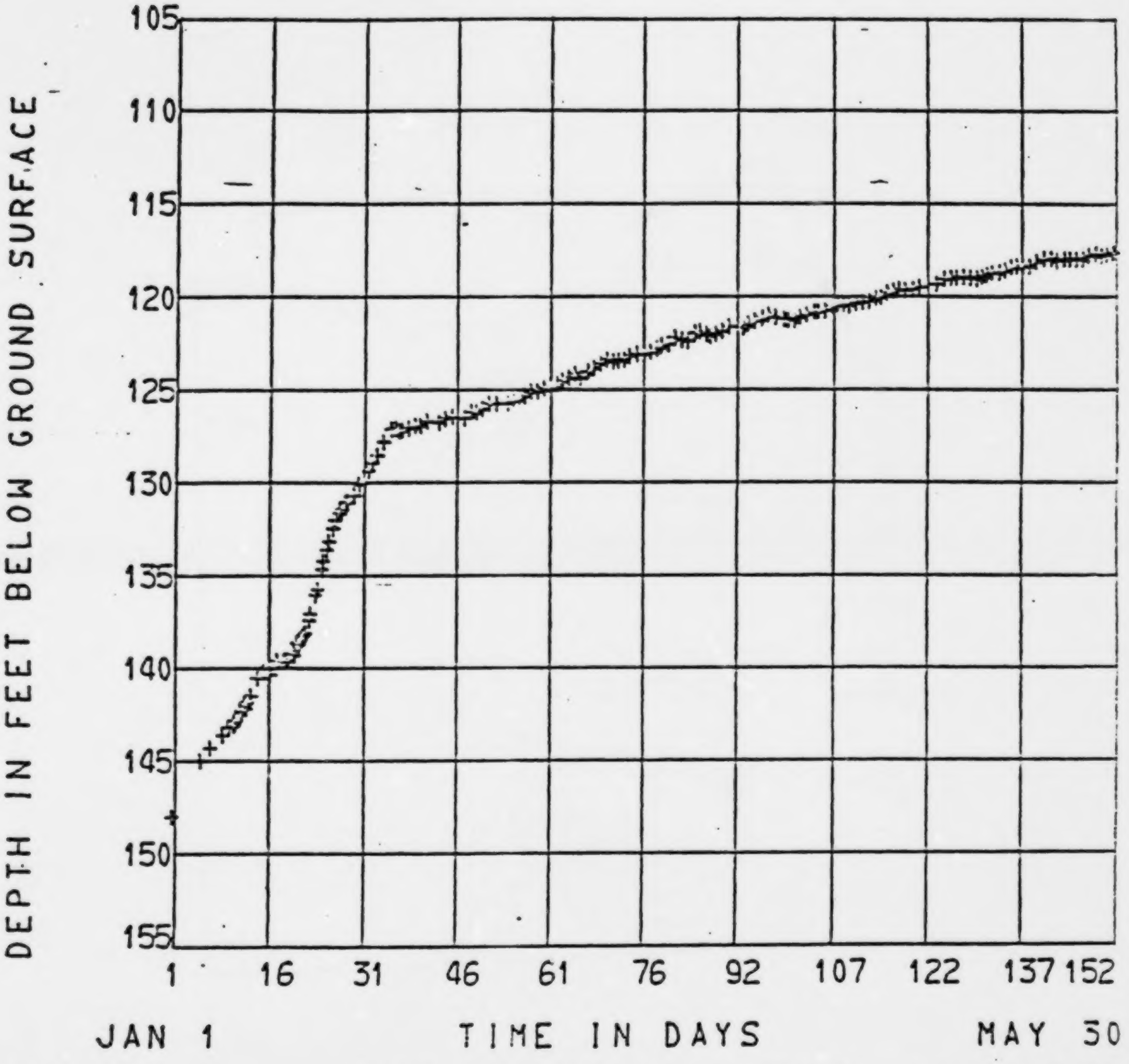


Upper Aquifer Storage Coefficient

198

(R.B.O.S.C. Feb. 1981)

Figure 78



TO-2 HYDROGRAPH UPPR AQUIFER

(Wright Water Engineers, Inc. Nov. 1972)

Figure 79

CE-709 UPPER, HYDROGRAPH
DECEMBER 1978 - NOVEMBER 1979, TRACT C-A

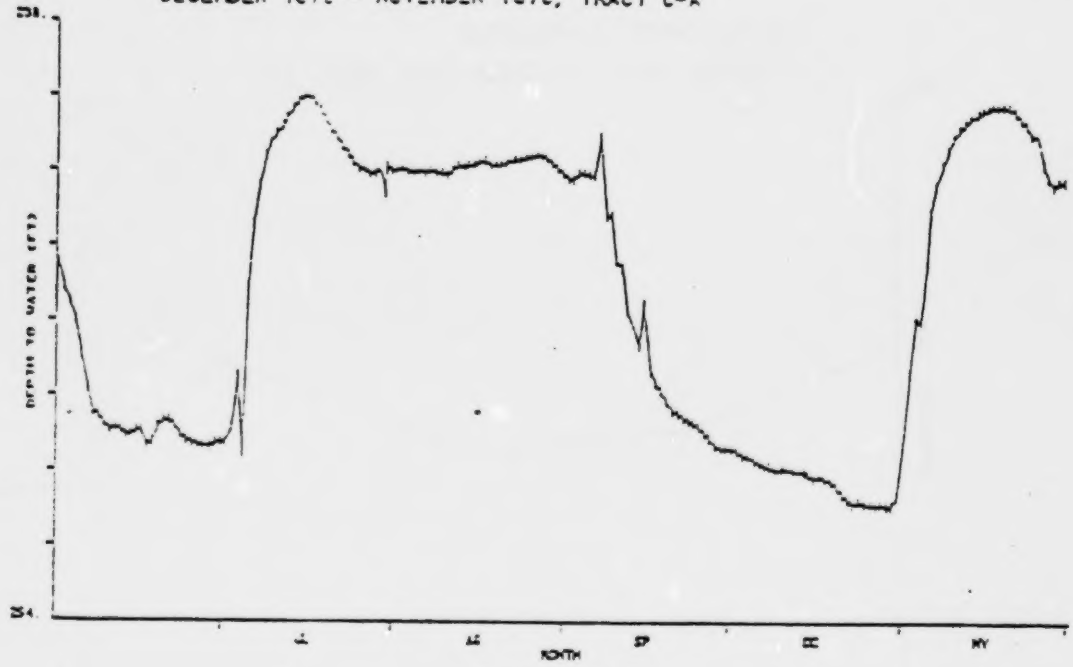
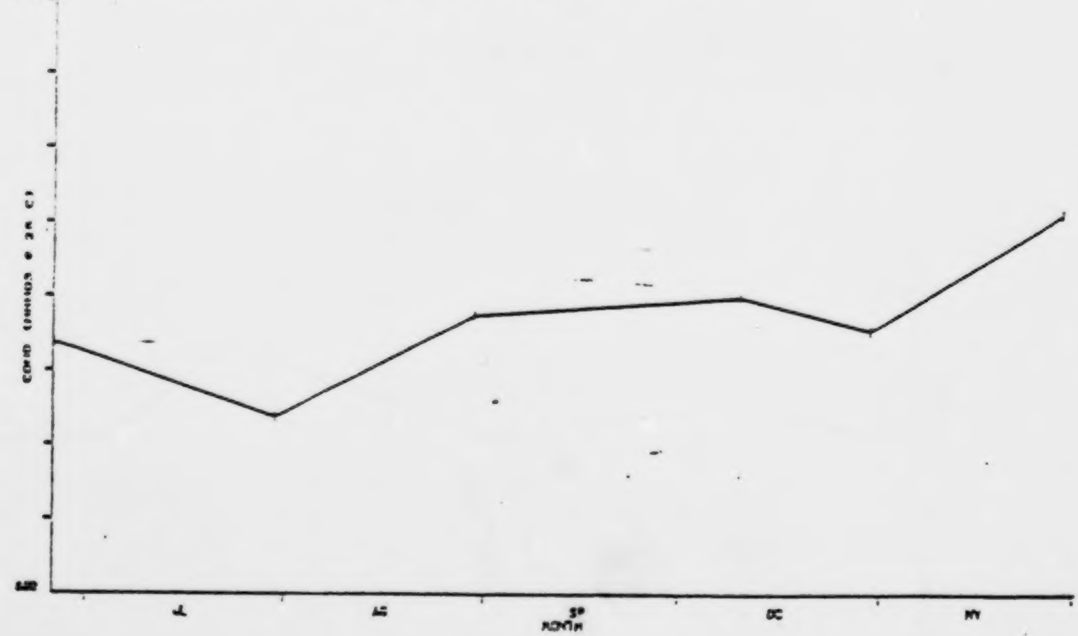


Figure 5-77

Fig. Ca-74

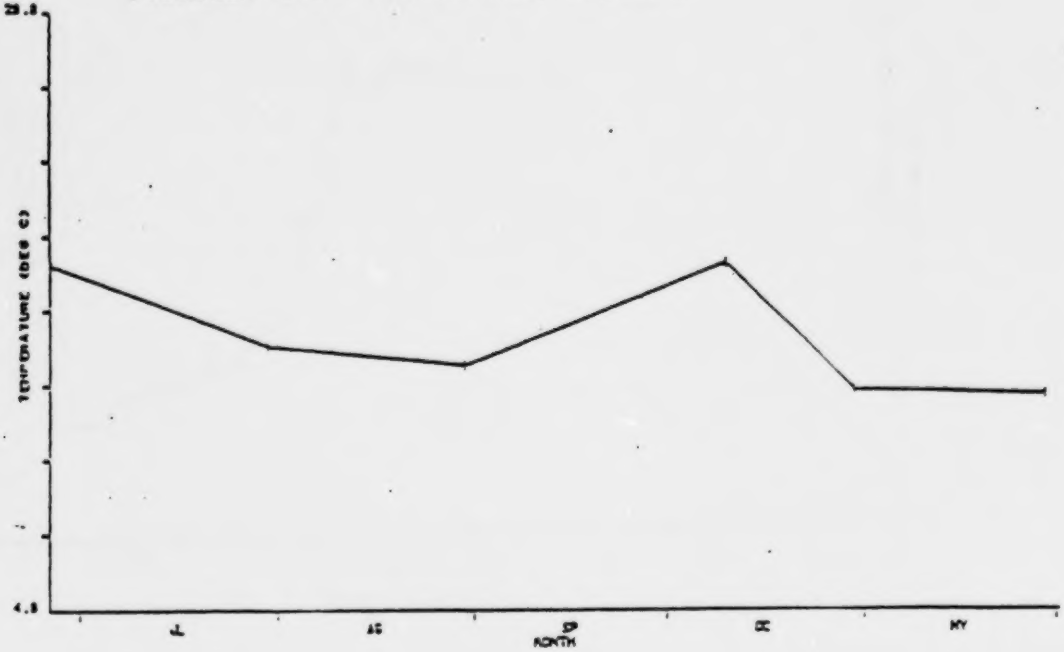
CE-709 UPPER, CONDUCTIVITY
DECEMBER 1978 - NOVEMBER 1979, TRACT C-A



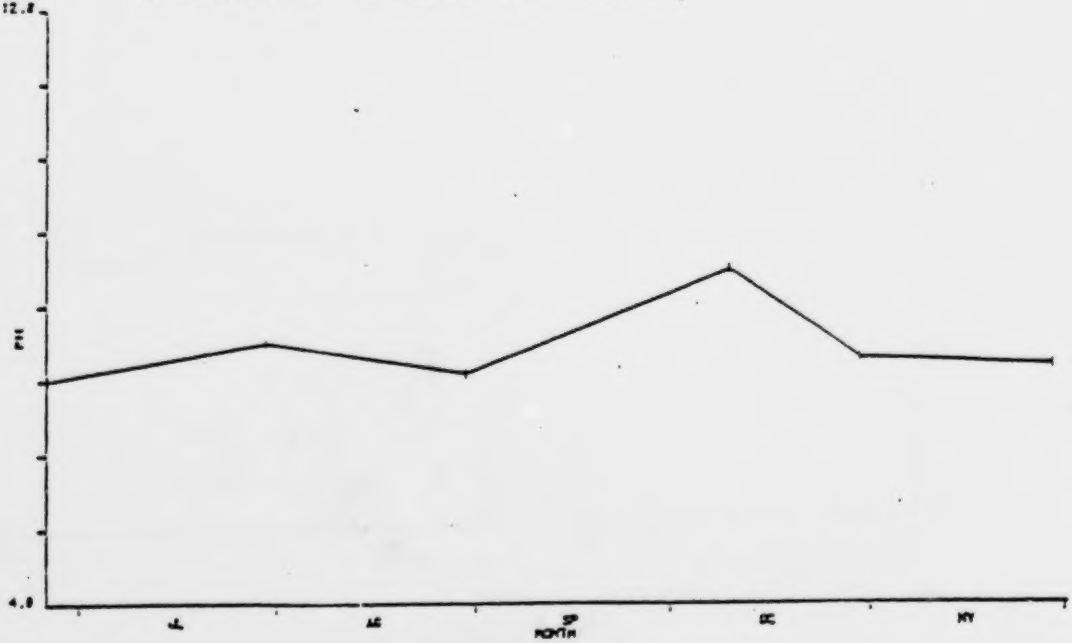
(R.B.O.S.C, Marc. 1980)

Figure 80

CE-709 UPPER, TEMPERATURE
DECEMBER 1978 - NOVEMBER 1979, TRACT C-A

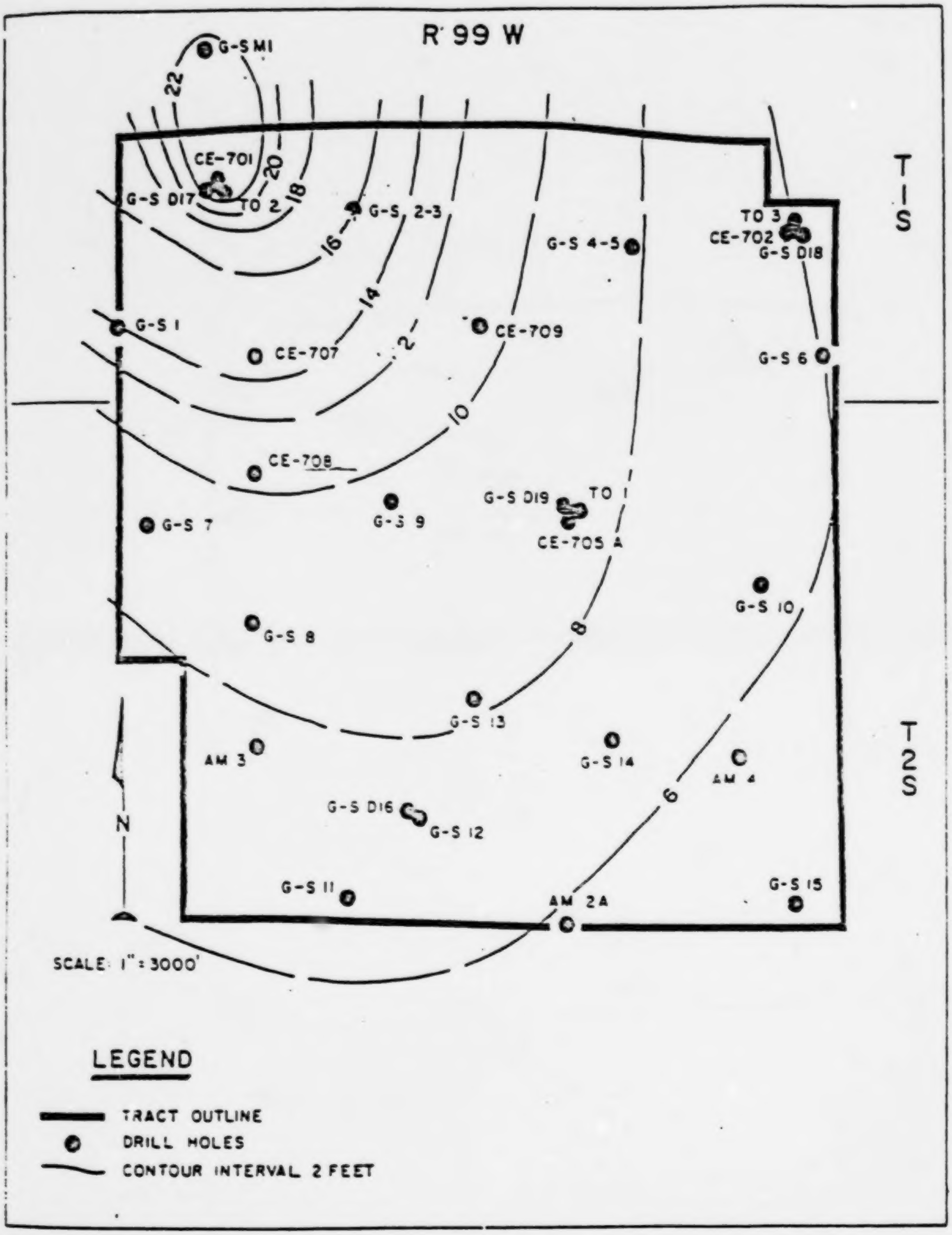


CE-709 UPPER, PH
DECEMBER 1978 - NOVEMBER 1979, TRACT C-A



201 (R.B.O.S.C. Mar. 1980)

Figure 81

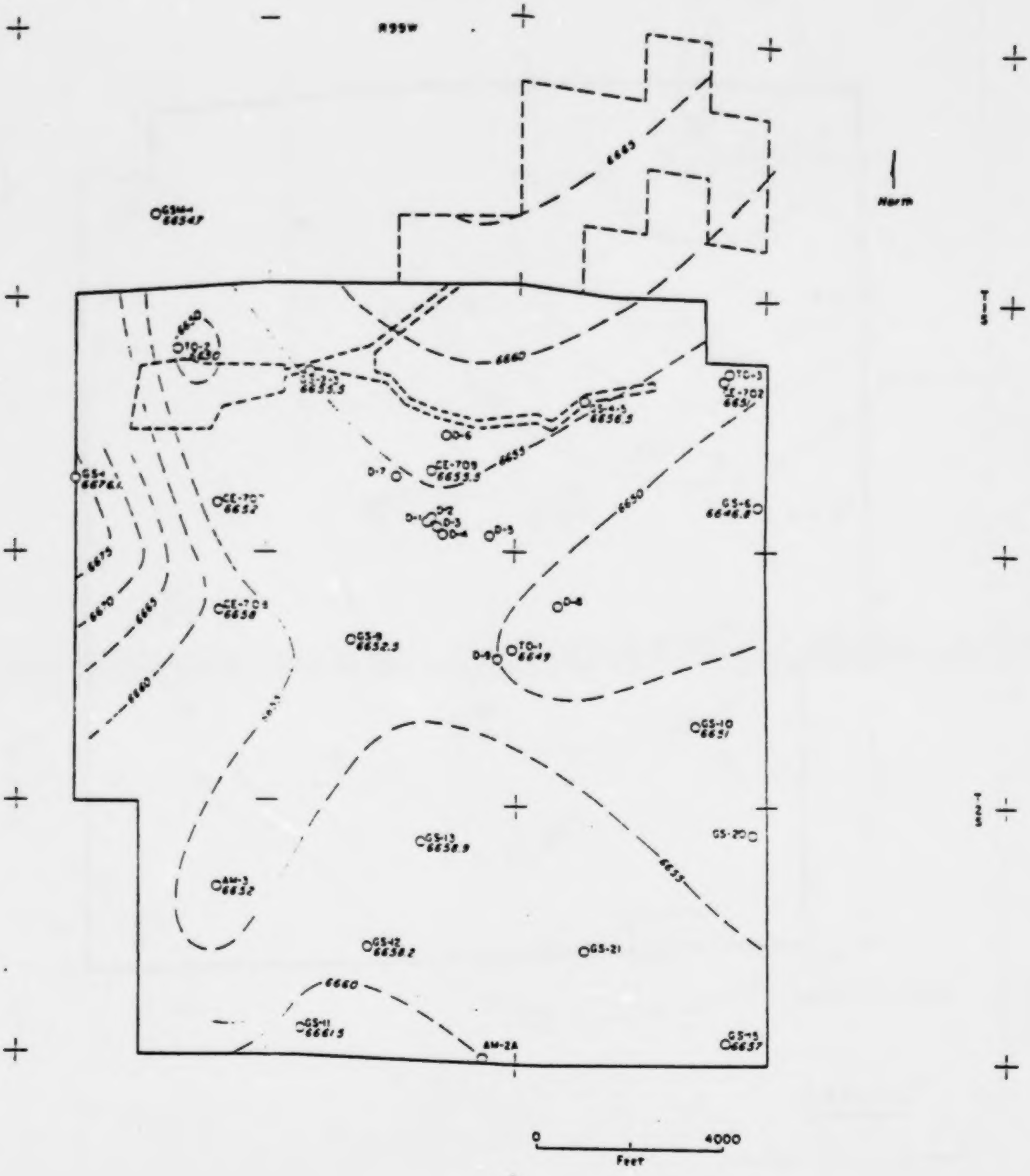


LOWER AQUIFER PUMPING TEST CONE OF DEPRESSION

(R.B.O.S.C. May 1977)

202

Figure 82

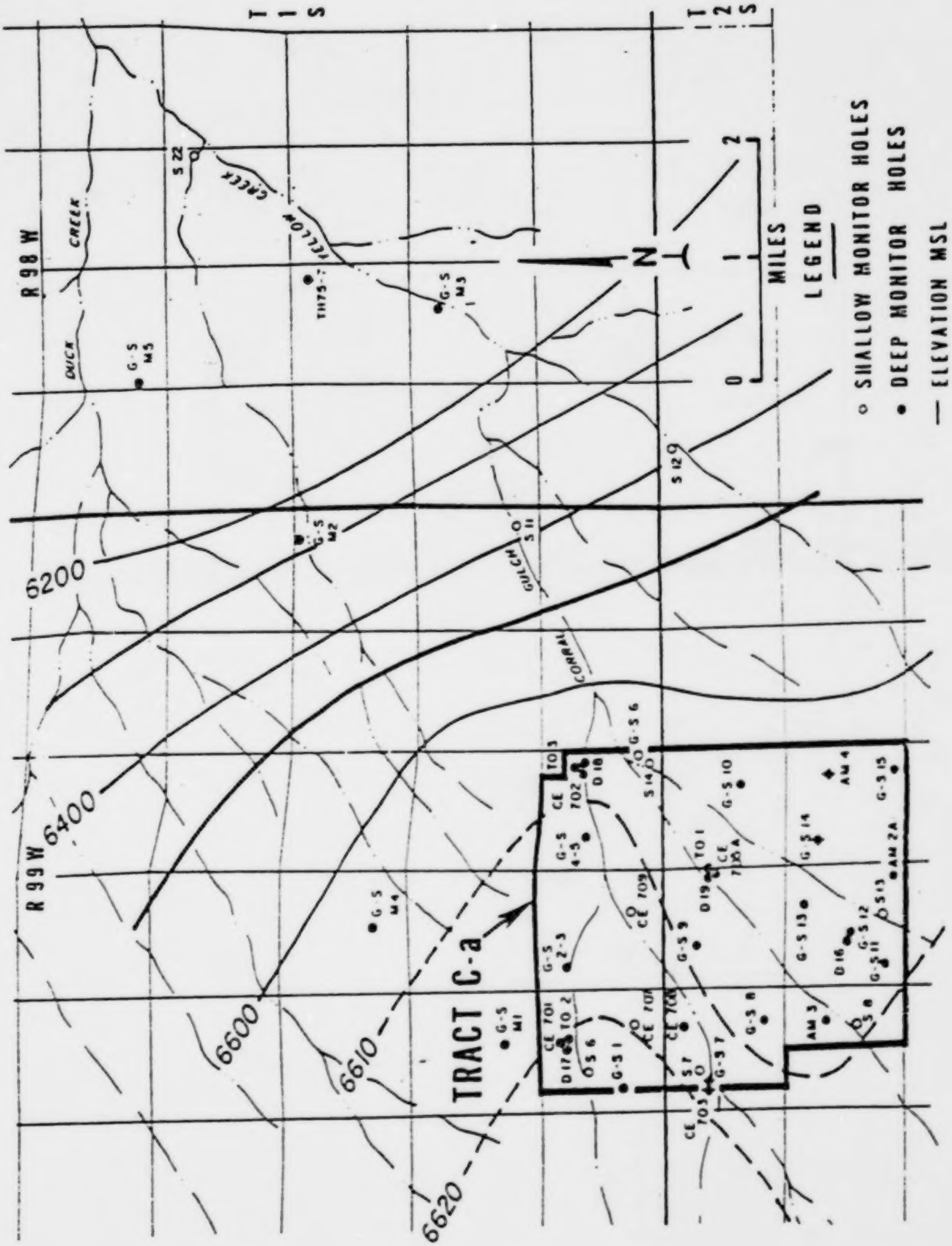


Lower Aquifer Piezometric Levels - January 11,1975

(R.B.O.S.C. Feb. 1981)

203

Figure 83

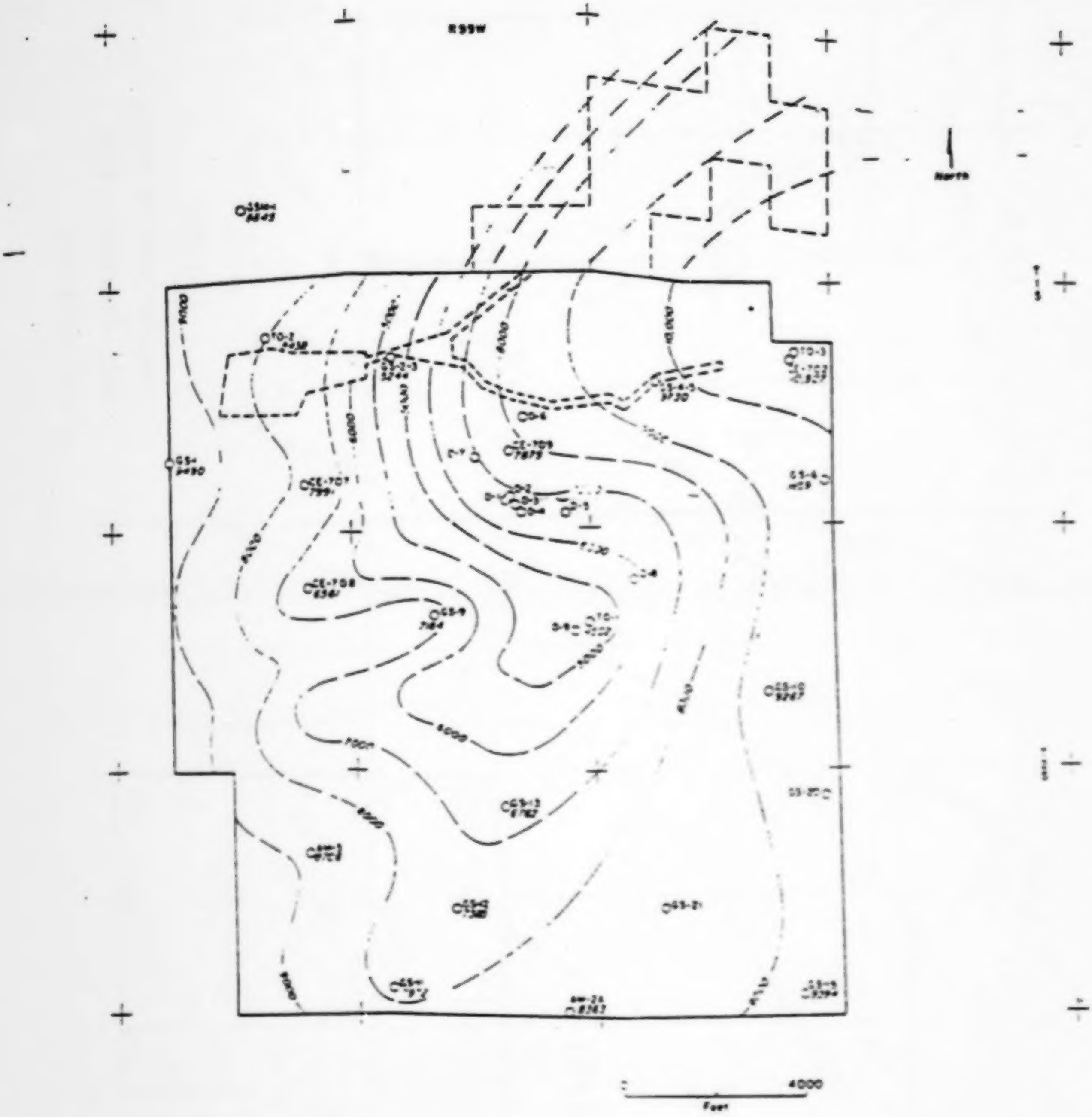


LOWER AQUIFER PIEZOMETRIC SURFACE, FALL 1976

(R.B,O,S.C, Sept, 1977)

204

Figure 84

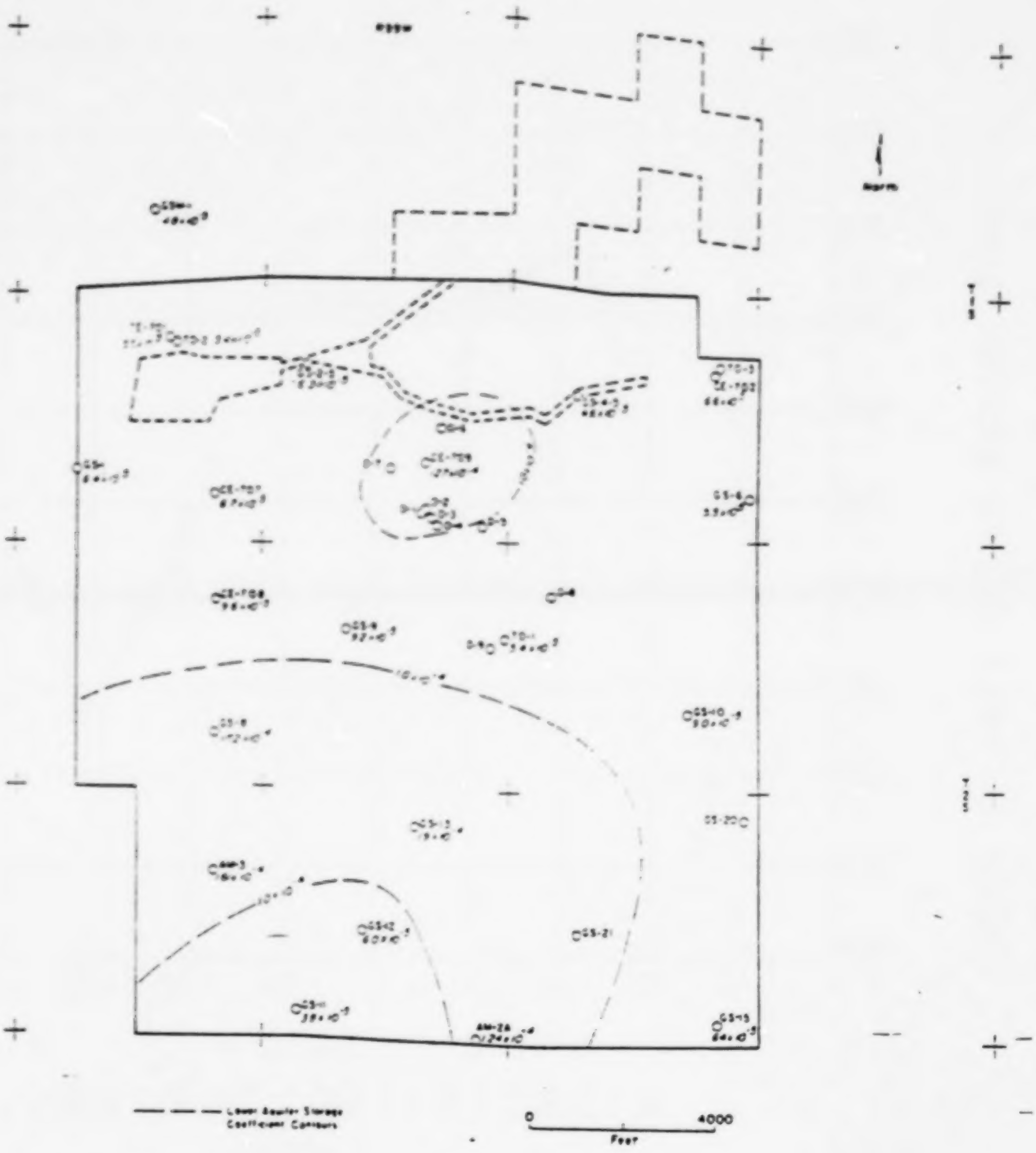


Lower Aquifer Transmissivity (GPD/ft)

(R.B.O.S.C., Feb. 1981)

205

Figure 85

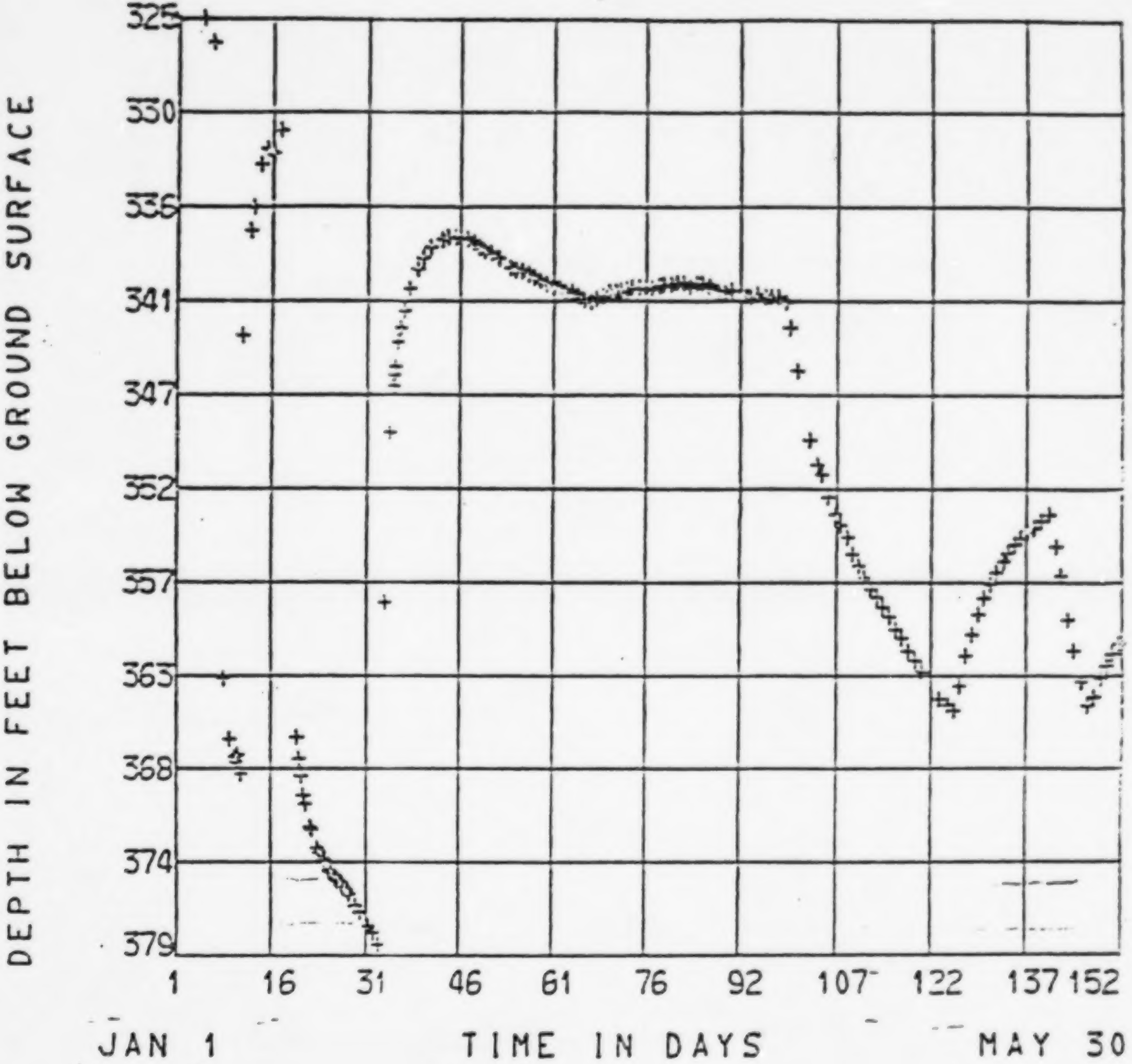


Lower Aquifer Storage Coefficient

206

(R.B.O.S.C. Feb. 1981)

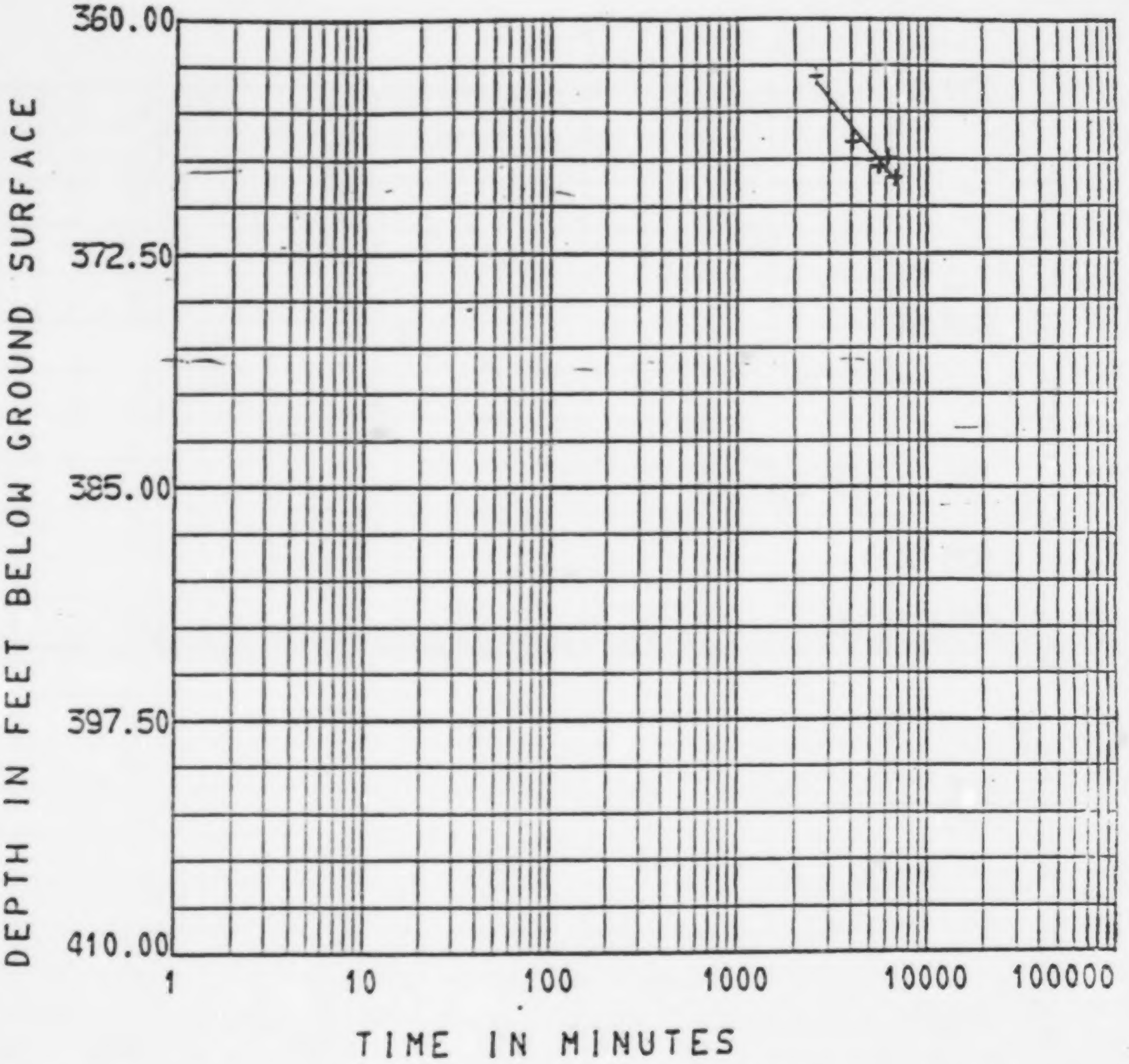
Figure 86



TO-2 HYDROGRAPH LOWR AQUIFER

(Wright Water Engineers, Inc., Jul. 1975)

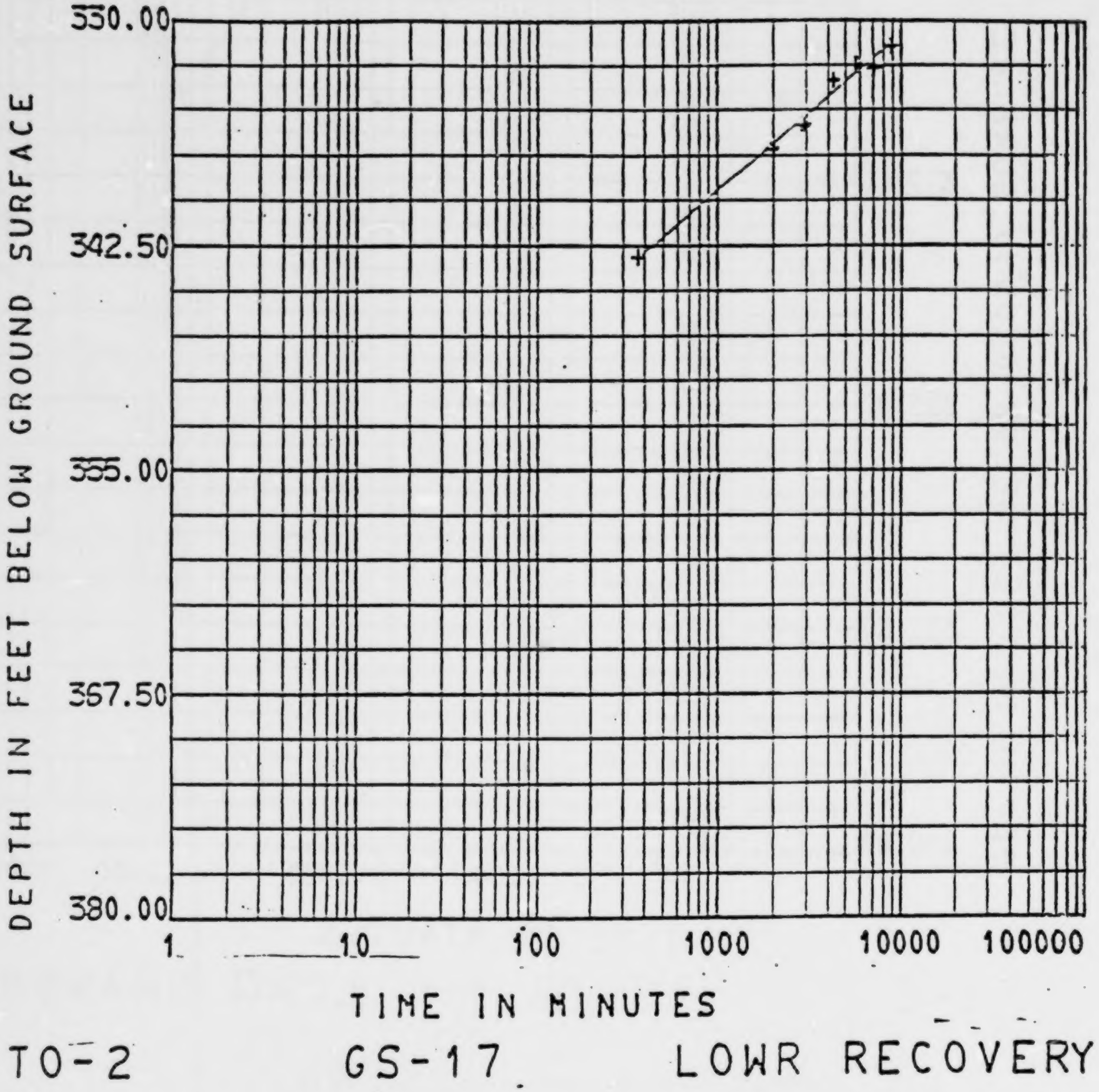
Figure 87



TO-2 GS-17 LOWR DRAWDOWN

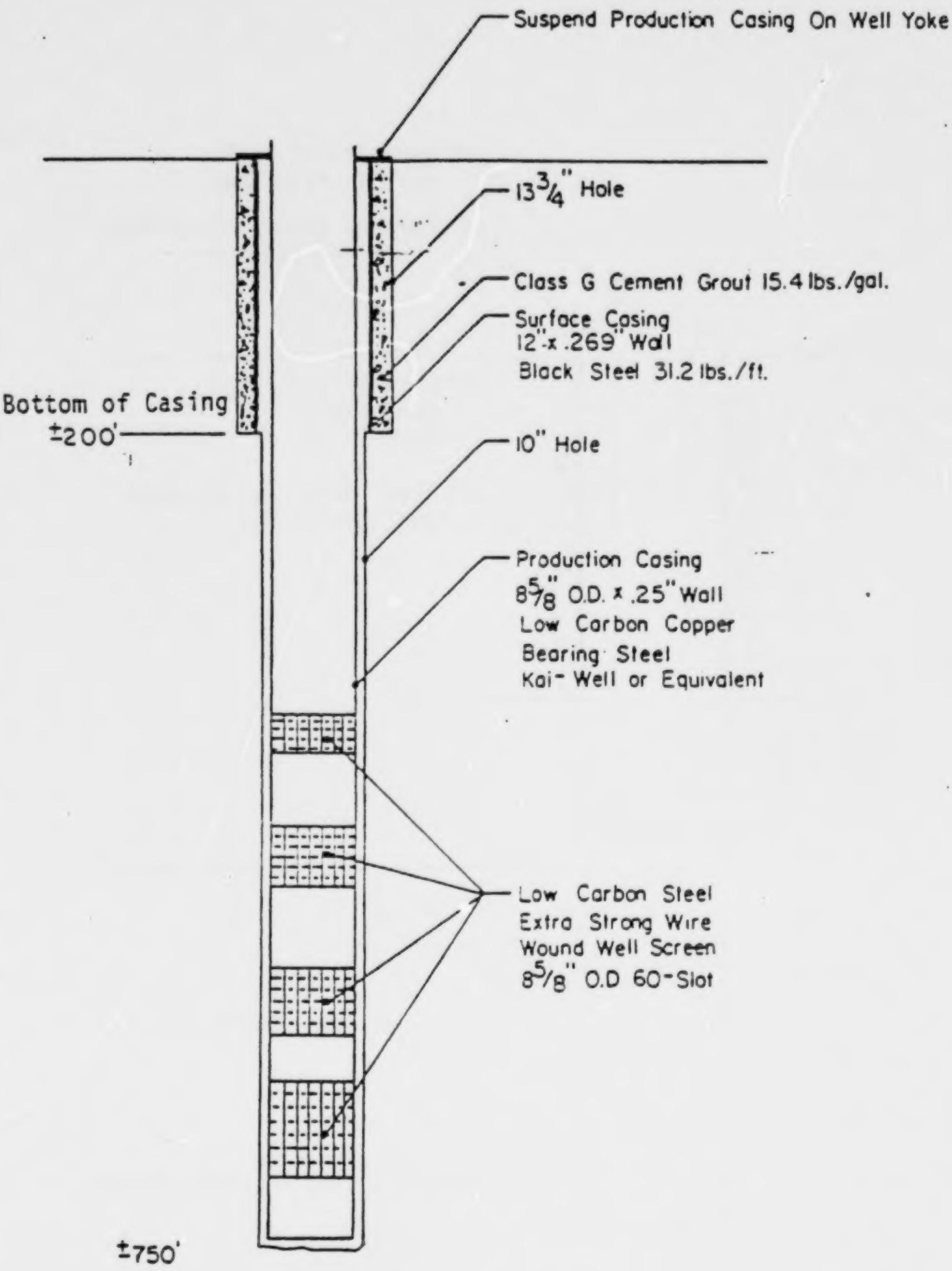
(Wright Water Engineers, Inc., July 1975)

Figure 88



(Wright Water Engineers, Inc., Jul. 1975)

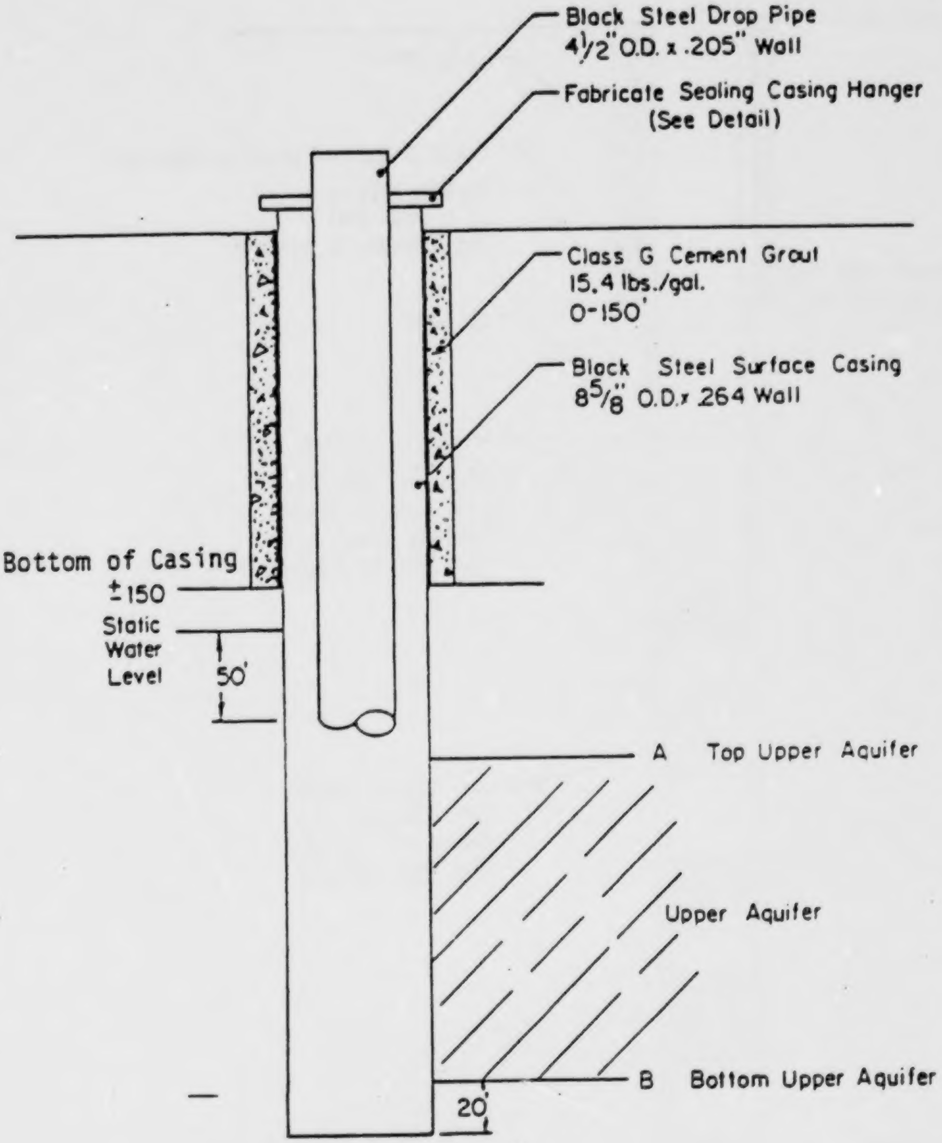
Figure 89



WELL DETAIL, TYPICAL DEWATERING WELL

(R.B.O.S.C., Sept. 1977)

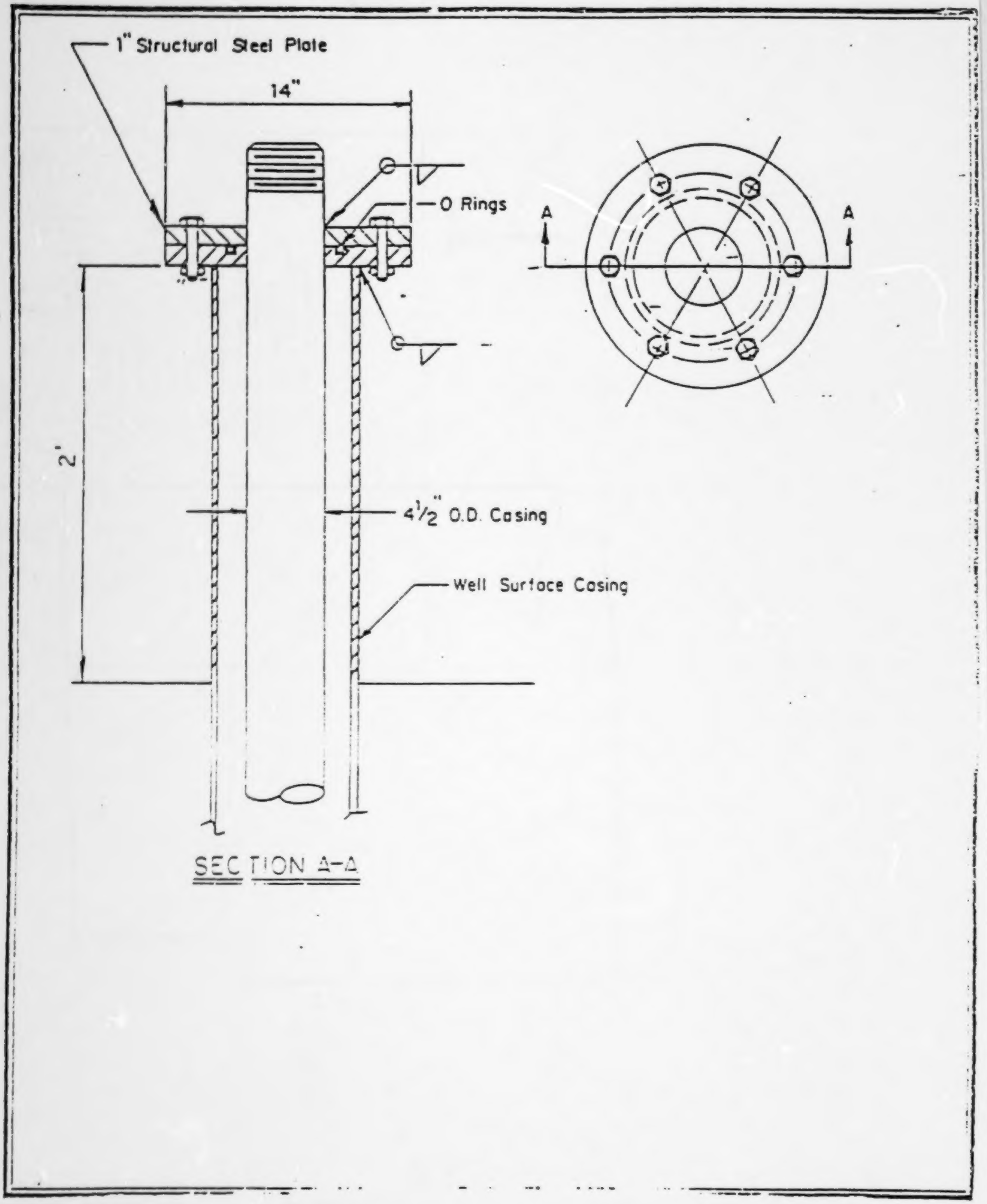
Figure 90



WELL DETAIL, TYPICAL NEW REINJECTION HOLE

(R.B.O.S.C., Sept. 1977)

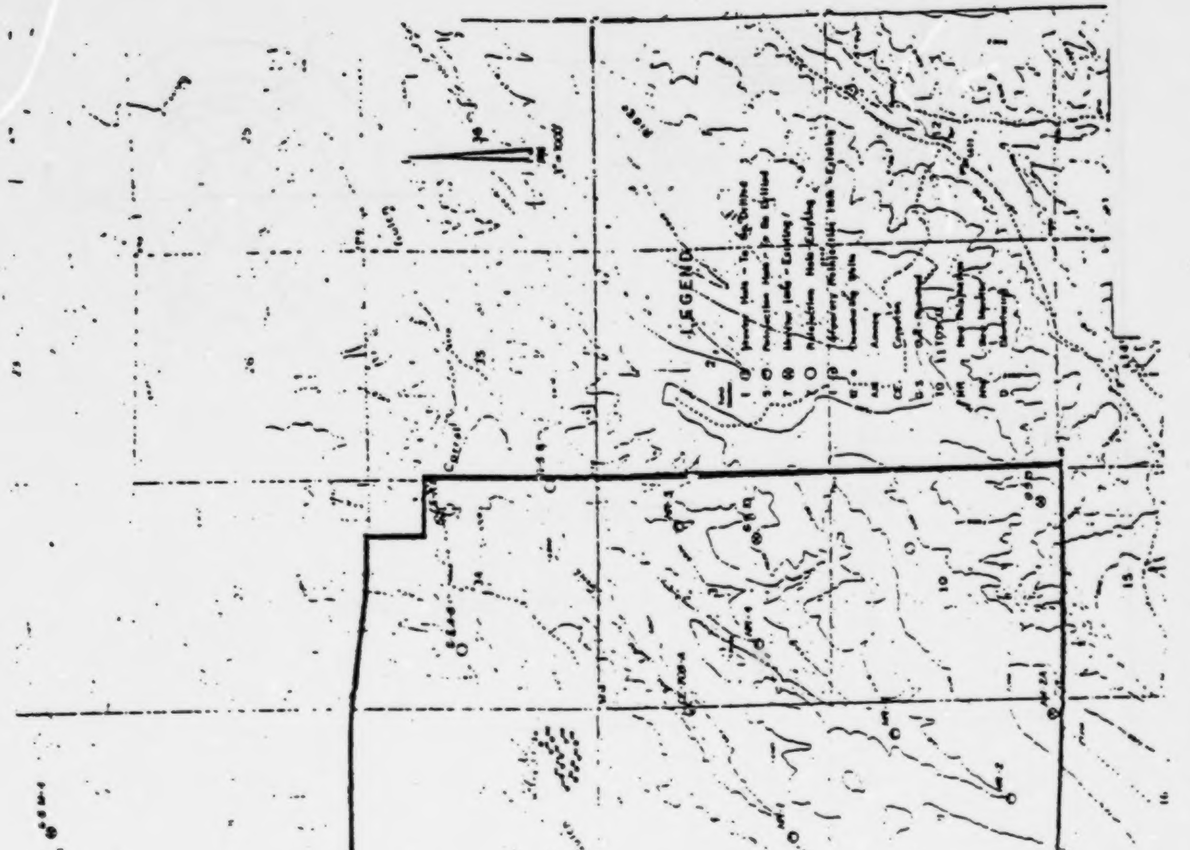
Figure 91



WELL HEAD DETAIL
(R.B.O.S.C., Sept. 1977)

212

Figure 92

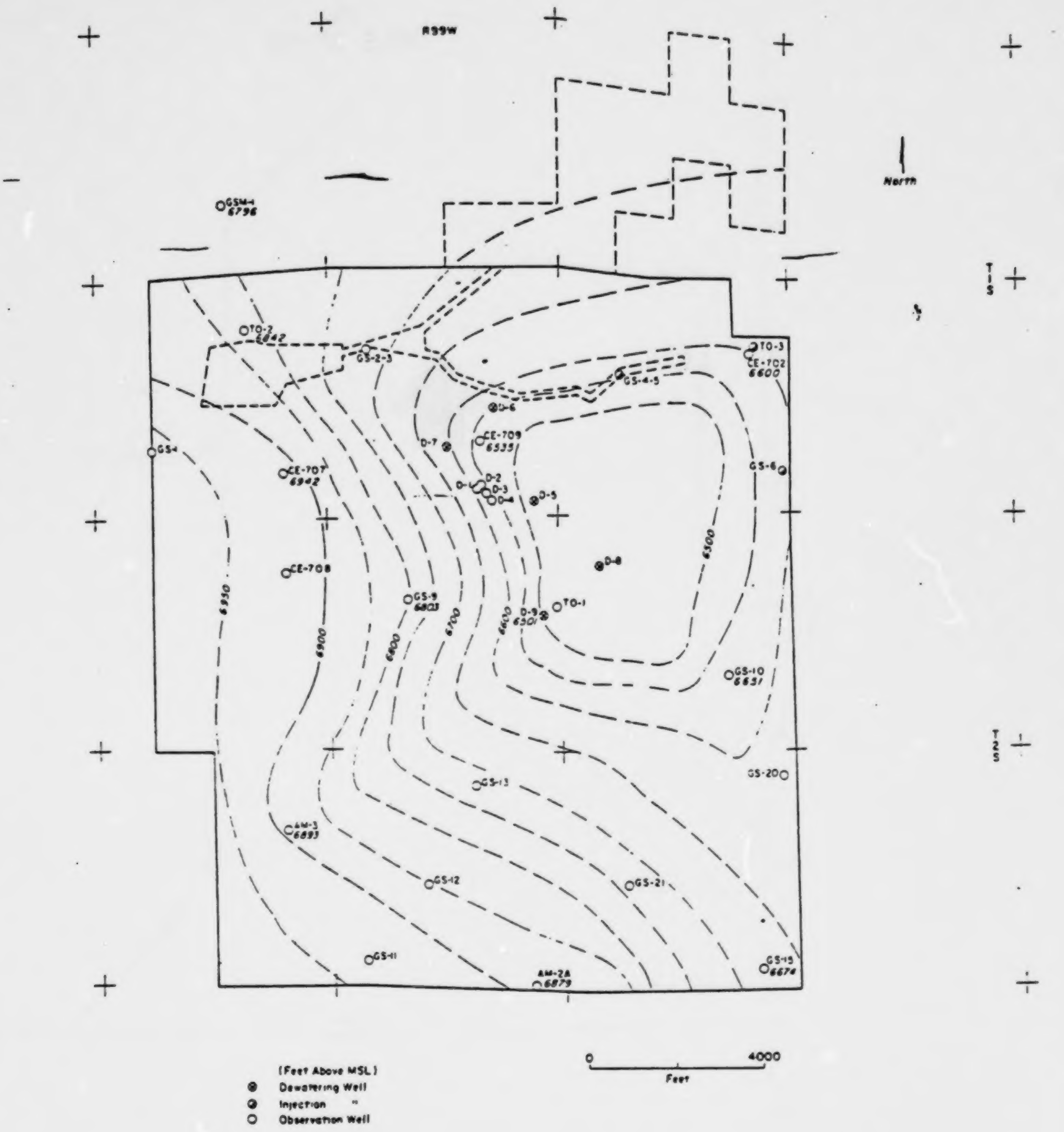

CONCEPTUAL WELL LAYOUT

213

Figure 93

(R.B.O.S.C., Sept. 1977)

Figure 93

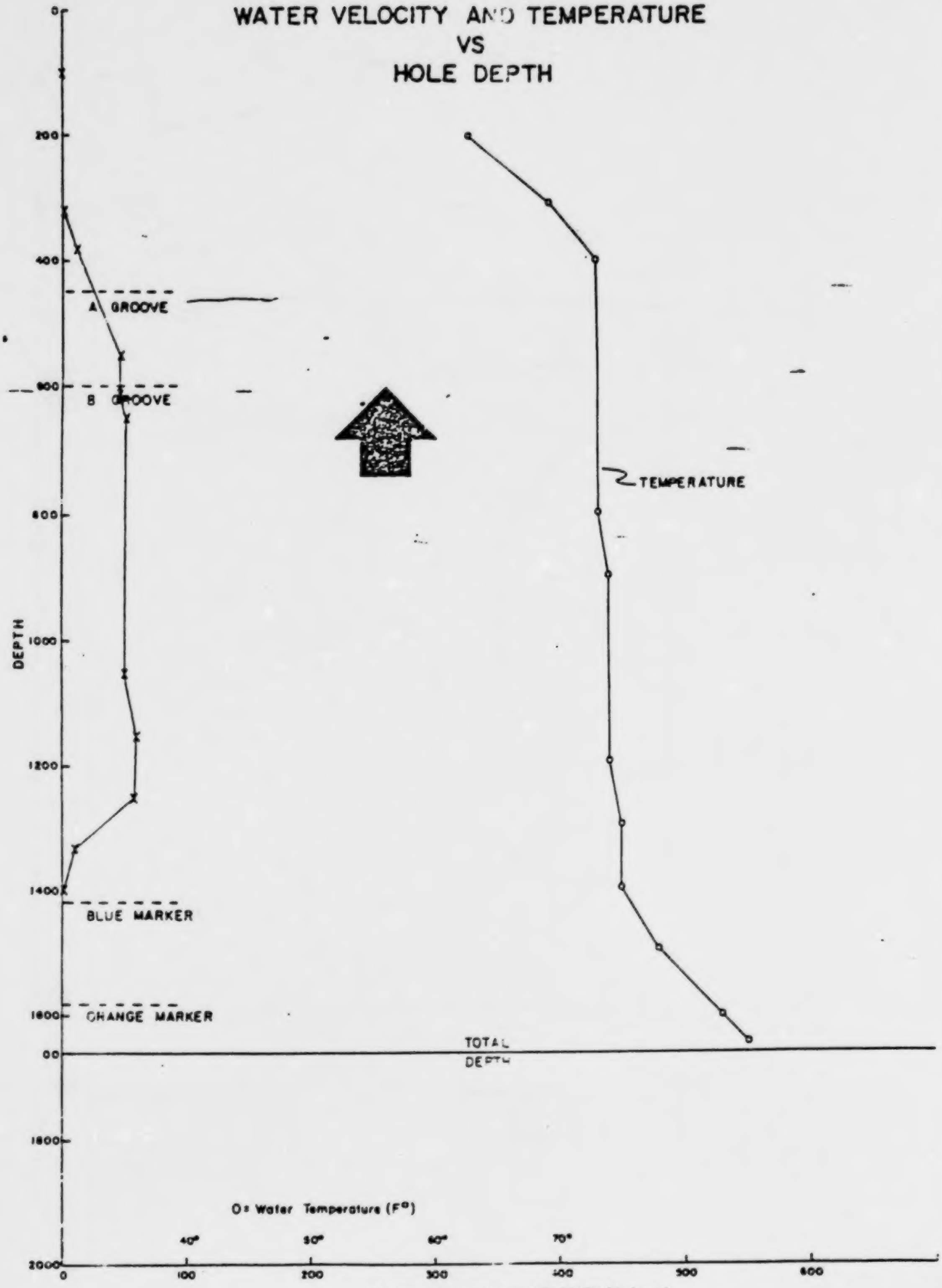


Upper Aquifer Piezometric Levels - November 30, 1979

(R.B.O.S.C., Feb. 1981)

214

Figure 94

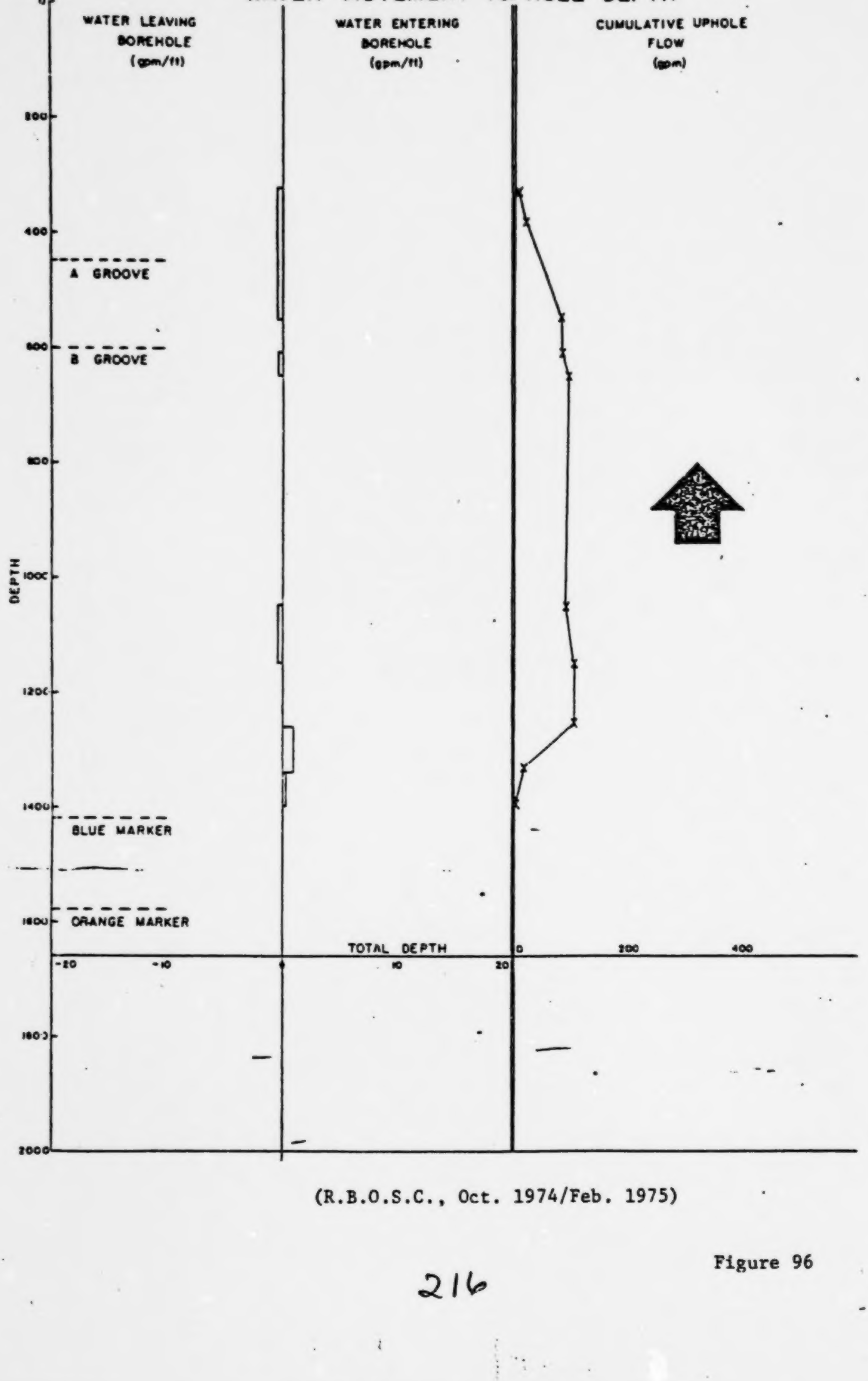


WATER VELOCITY AND TEMPERATURE VS HOLE DEPTH

215 (R.B.O.S.C., Oct. 1974/Feb. 1975)

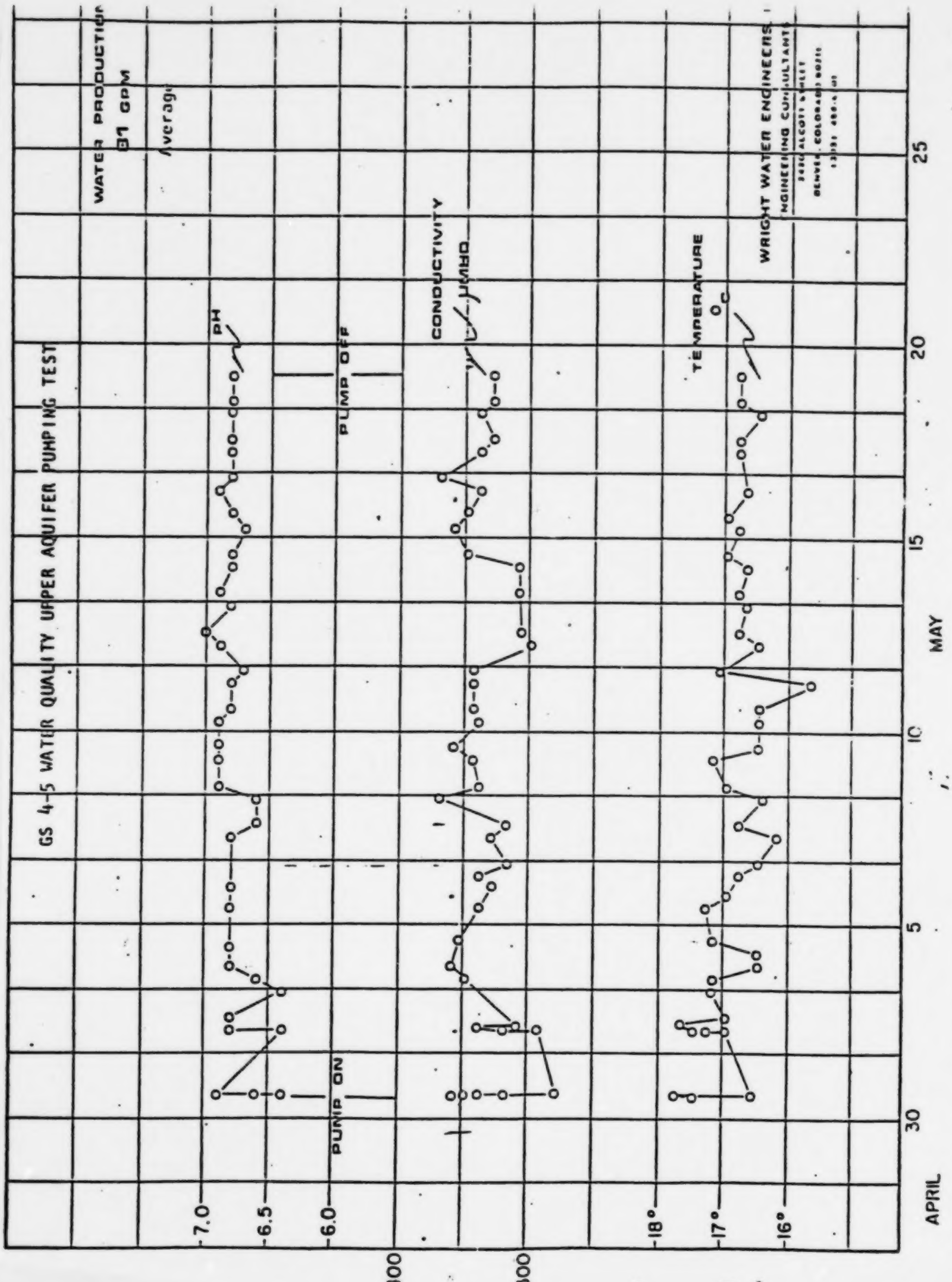
Figure 95

WATER MOVEMENT VS. HOLE DEPTH



(R.B.O.S.C., Oct. 1974/Feb. 1975)

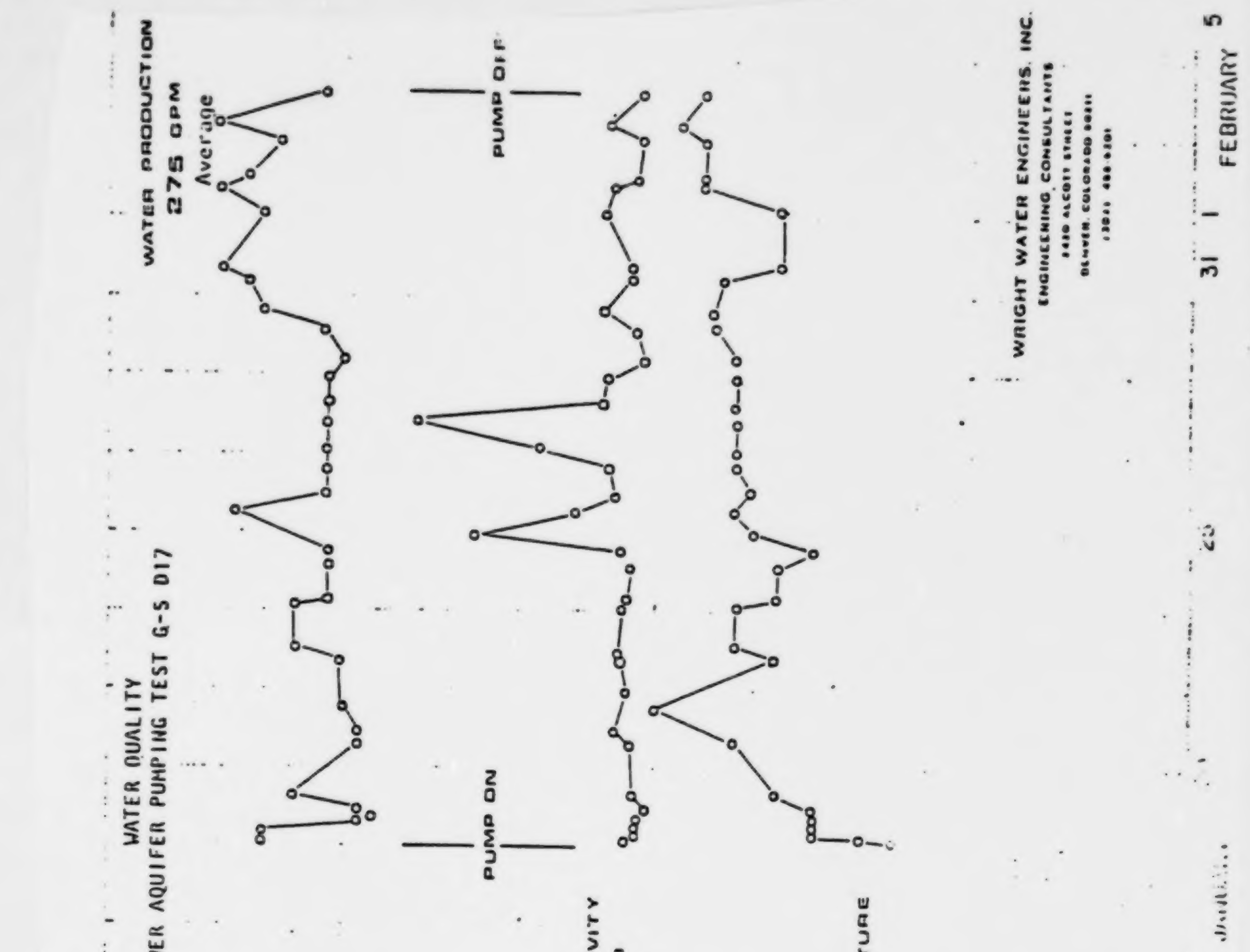
Figure 96



(R.B.O.S.C., Jul. 1975)

Figure 97

217



(R.B.O.S.C., Jul, 1975) p. 218 Figure 98

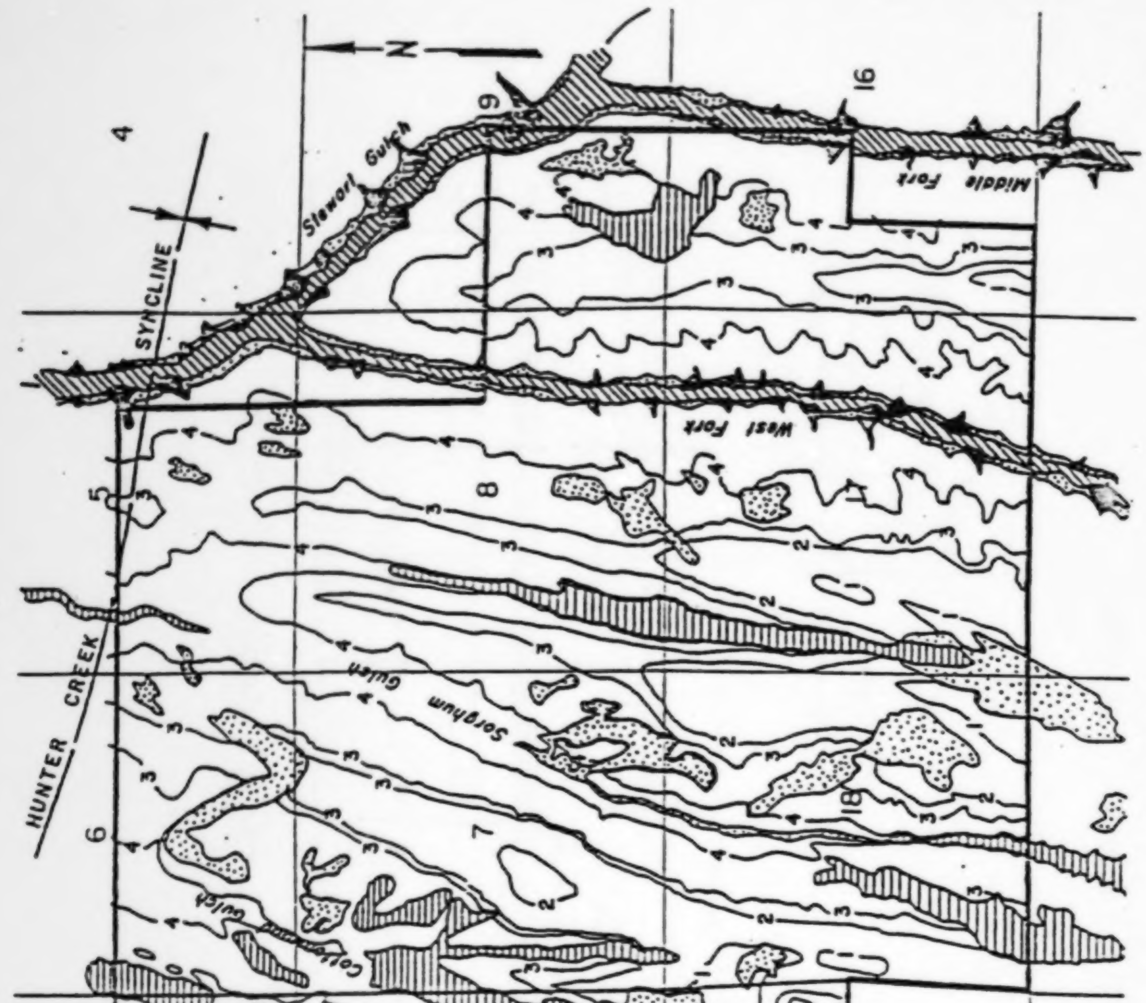


Figure 99 SURFACE GEOLOGIC MAP
TRACT C-b AND VICINITY
(Cb Shale Oil Venture, 1975, Environmental Baseline Program, Annual Summary 1)

219

Figure 99

Figure 100

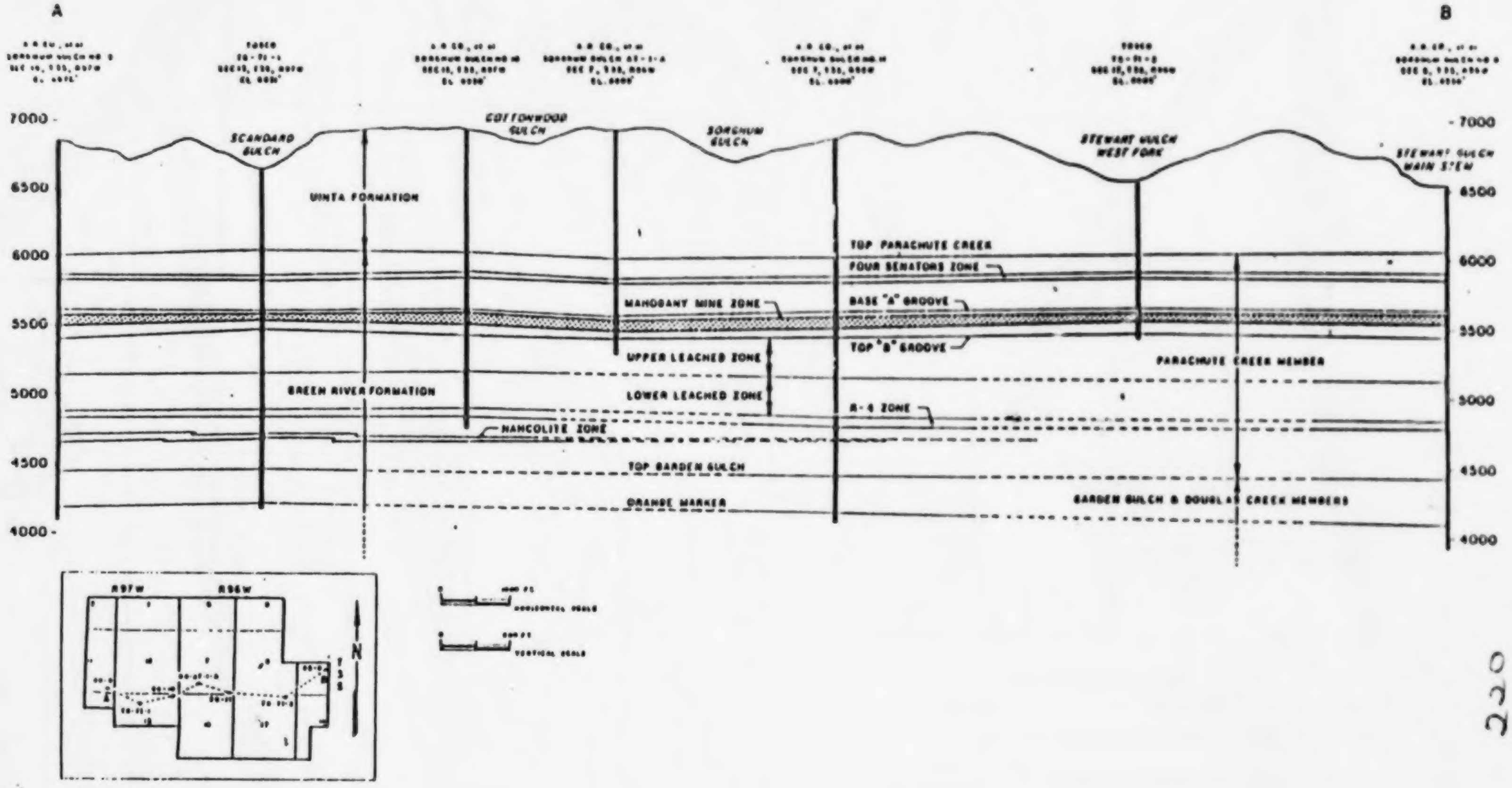
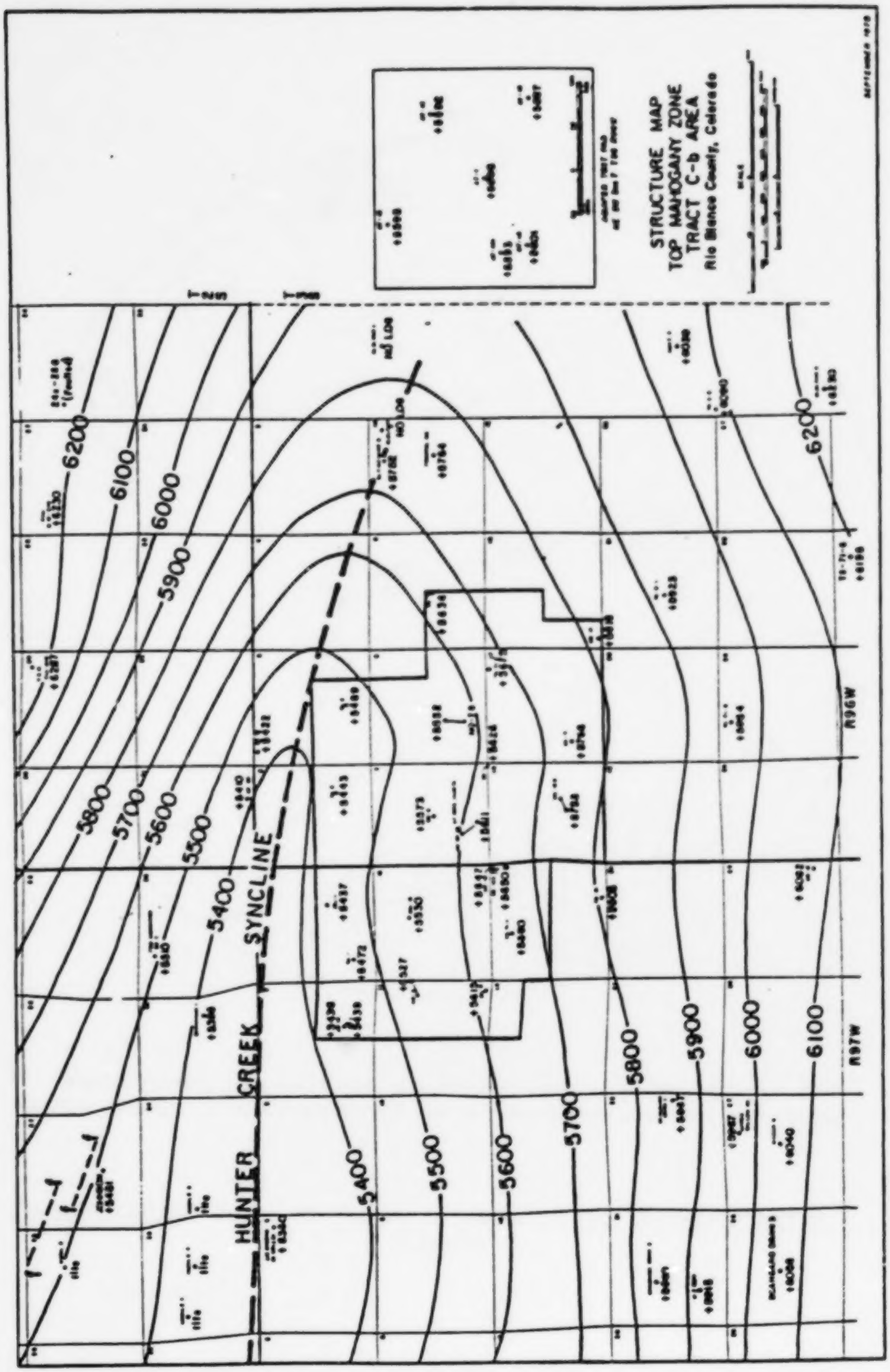


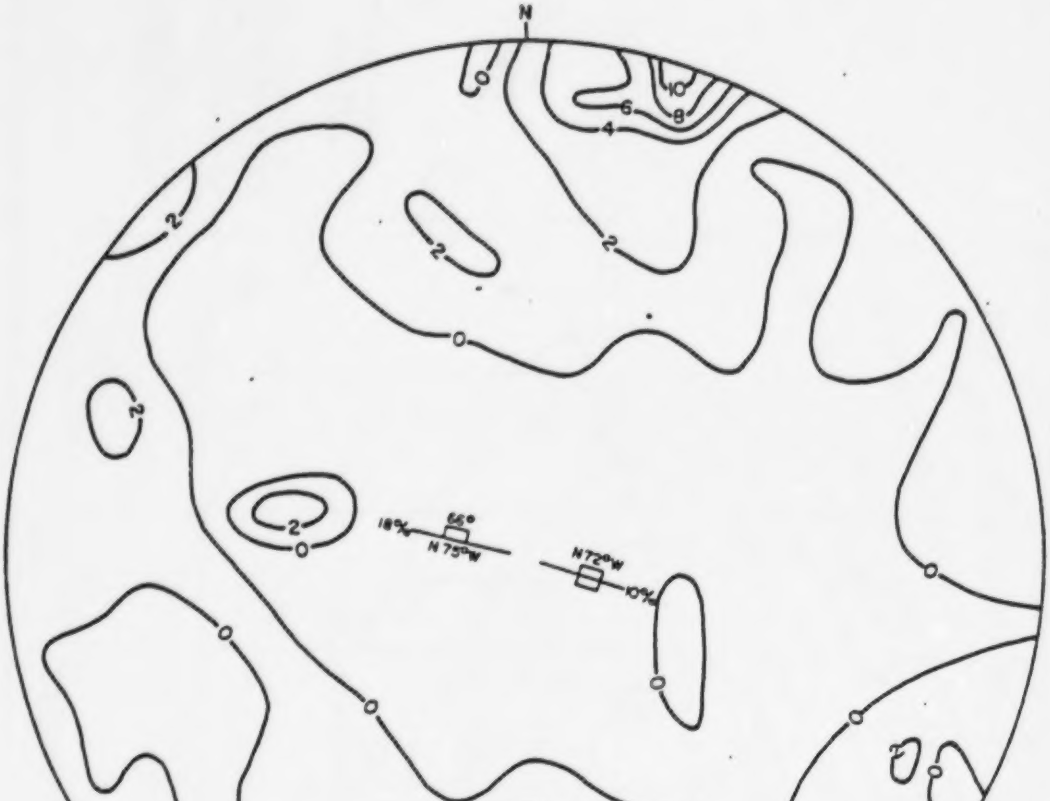
Figure 100 EAST-WEST STRATIGRAPHIC CROSS SECTION
TRACT C-b

(ibid.)



(Cb Shale Oil Project, 1978, Reinjection Application Permit)

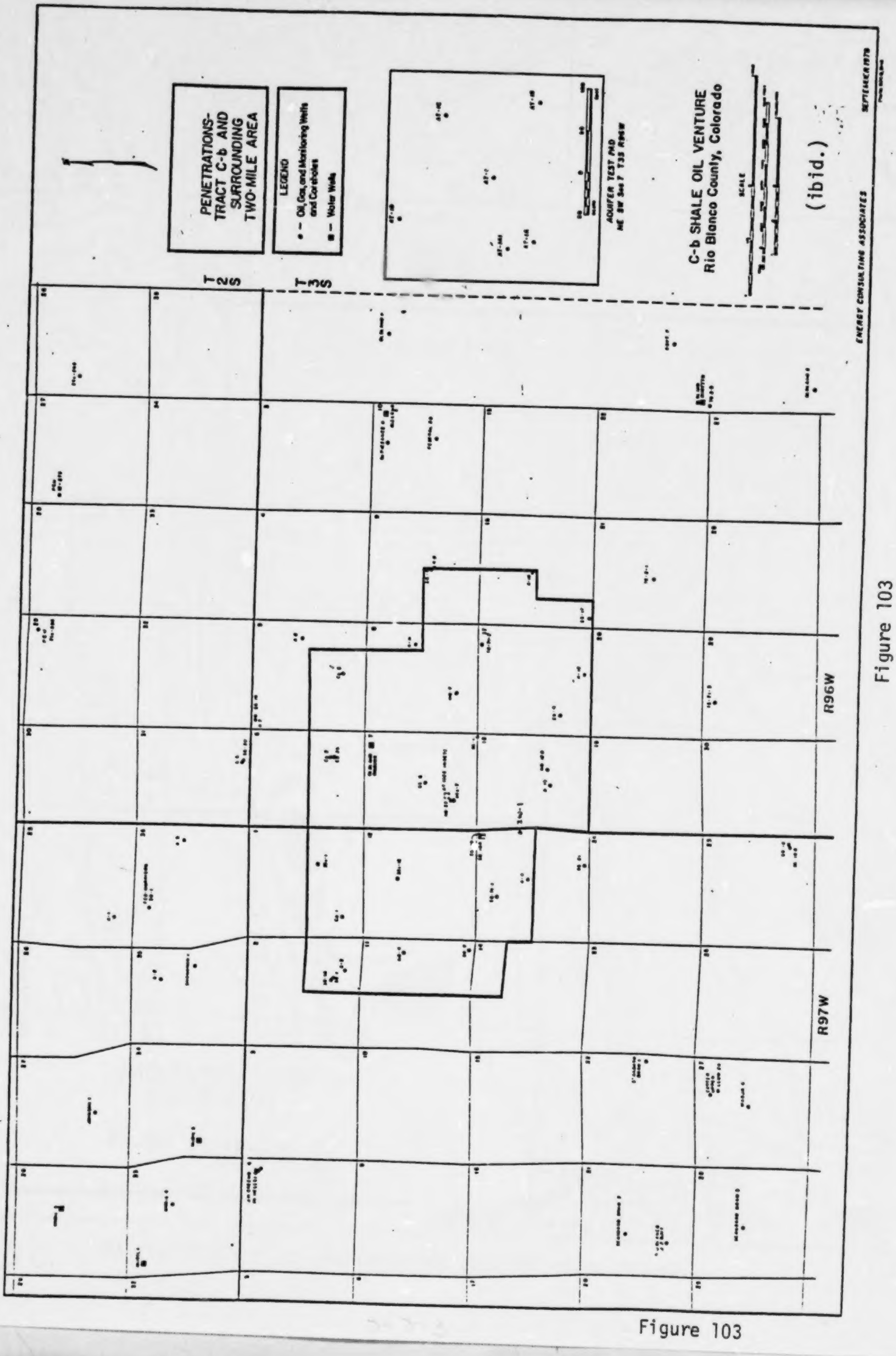
Figure 101



Data from 39 locations on Tract Cb plotted on lower hemisphere. Contours indicate percent of all joint poles that lie within an area equal to one percent of total area of diagram.

STEREOGRAPHIC NET CONTOUR DIAGRAM OF JOINT MEASUREMENTS
(ibid.)

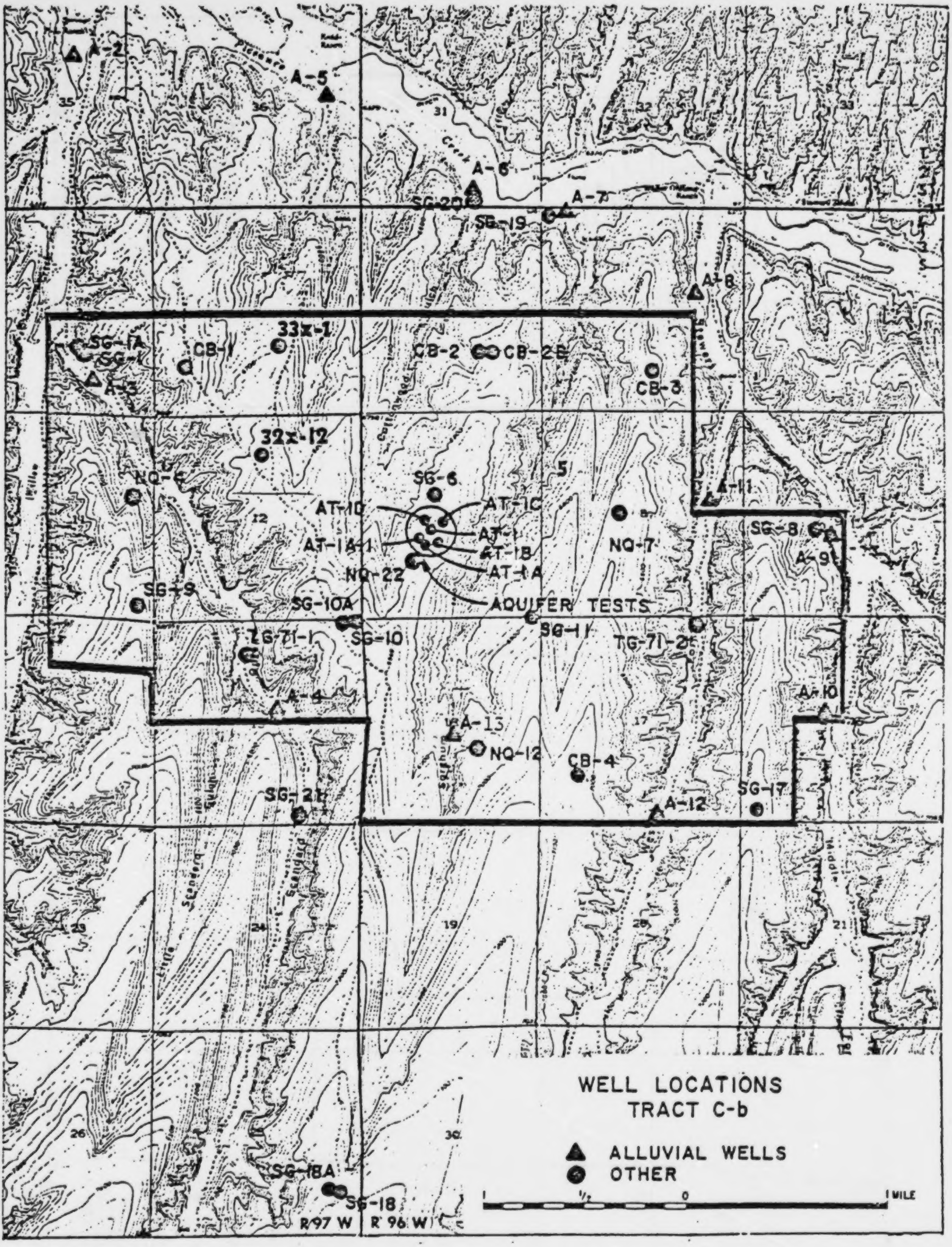
Figure 102



(ibid.)

Figure 103

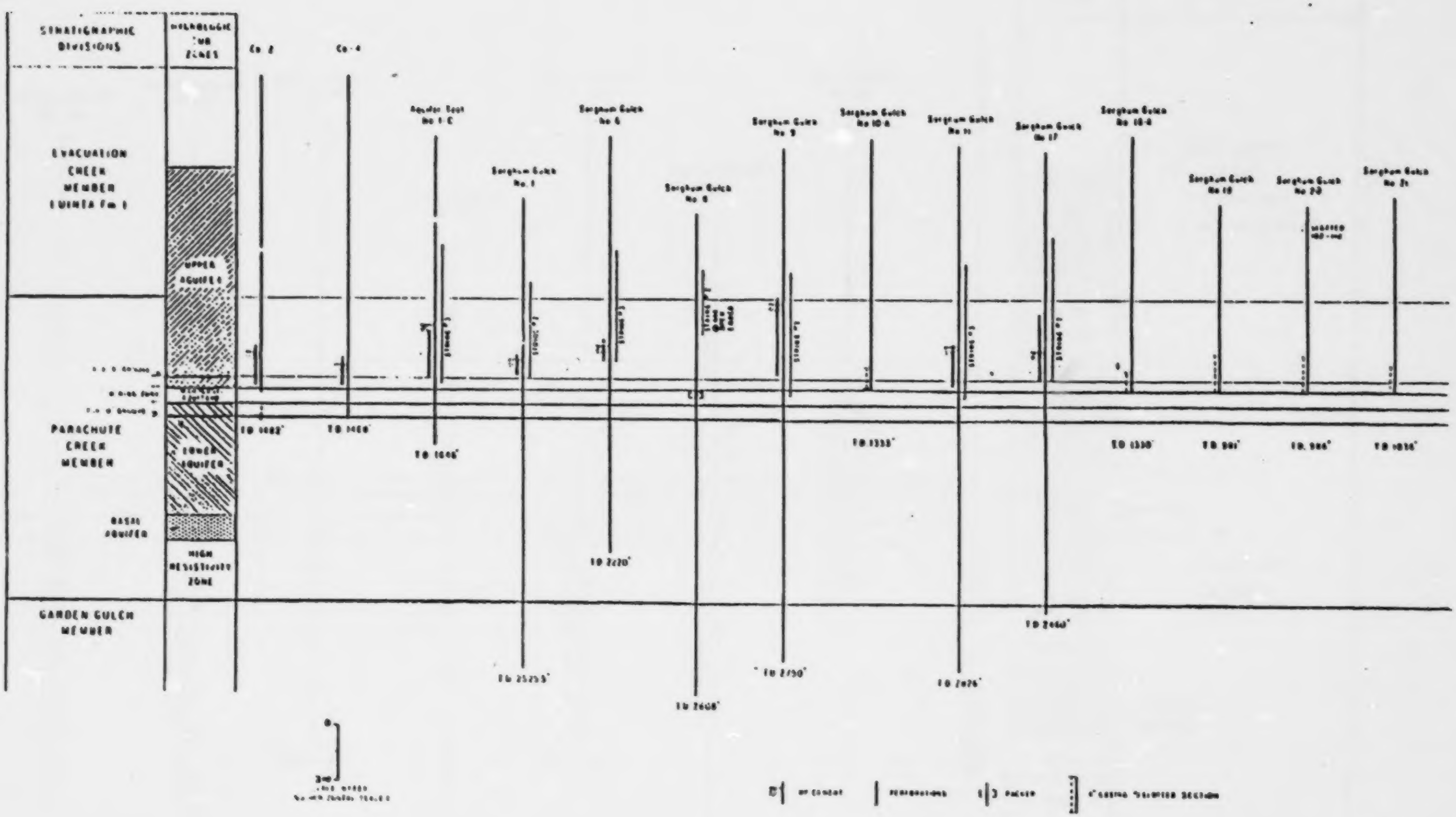
Figure 103



(Cb Oil Shale Venture, 1975, Summary Quarterly Report #5)

Figure 104

WELL COMPLETIONS IN
THE UPPER AQUIFER.
Through Sept 1975



(Cb Shale Oil Venture, 1975, Environmental Baseline Program
Annual Summary 1)

Figure 105

WELL COMPLETIONS IN
THE LOWER AQUIFER.
(through Sept. 1975)

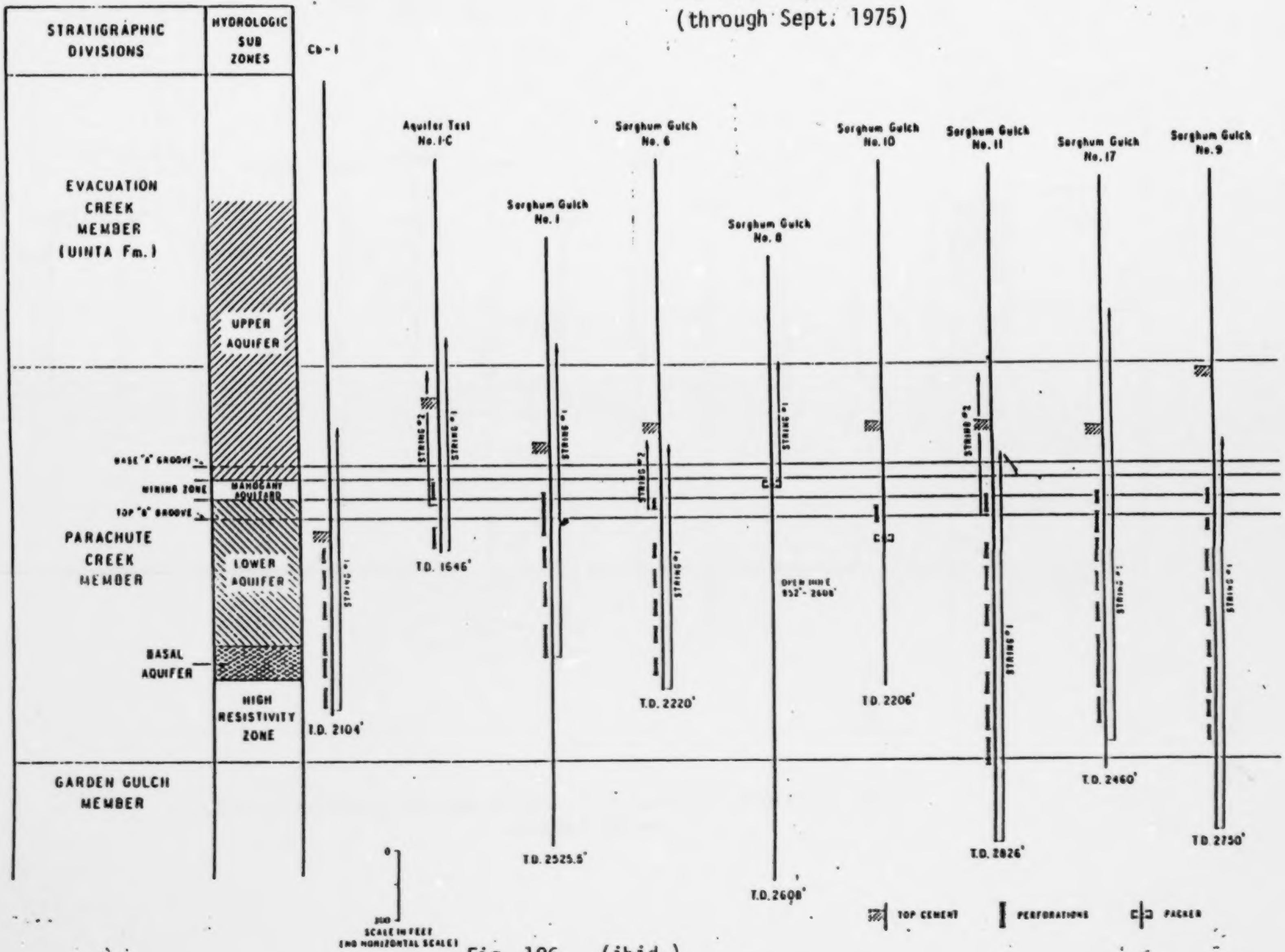


Fig. 106 (ibid.)

Figure 106

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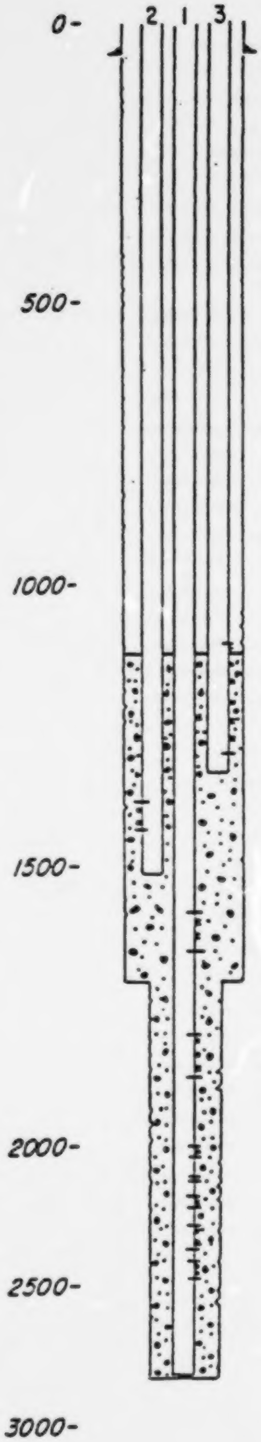
SG-11
C-b Tract
Section 7, T3S, R96W



8⅝" at 60' Cemented to surface

#1 String to 2820' PBTD 2813'

#2 String to 1511'

#3 String to 1327'

Cemented 9/14/74 w/230 sx Howco Light + 10#/sx
Gilsonite + 0.3% LWL

Cement Top by Log - 1120

Perforations:
#1 String 1580-1650', 1790-1870, 1995-2024, 2100-05, 2170-90', 2300-15, 2325-60', 2400-20', 2435-60' } 2 Shot/ft.
#2 String 1365-1435' 1-9/16" Hyper Jets at 1 Shot/ft.
#3 String 1100-1290' 1-9/16" Hyper Jets at 1 Shot/ft.

7⅞" Hole to 1703'

4⅞" Hole to 2826'

(Cb Shale Oil Venture, 1974, Summary Quarterly
Reports #1 through #9

Figure 107

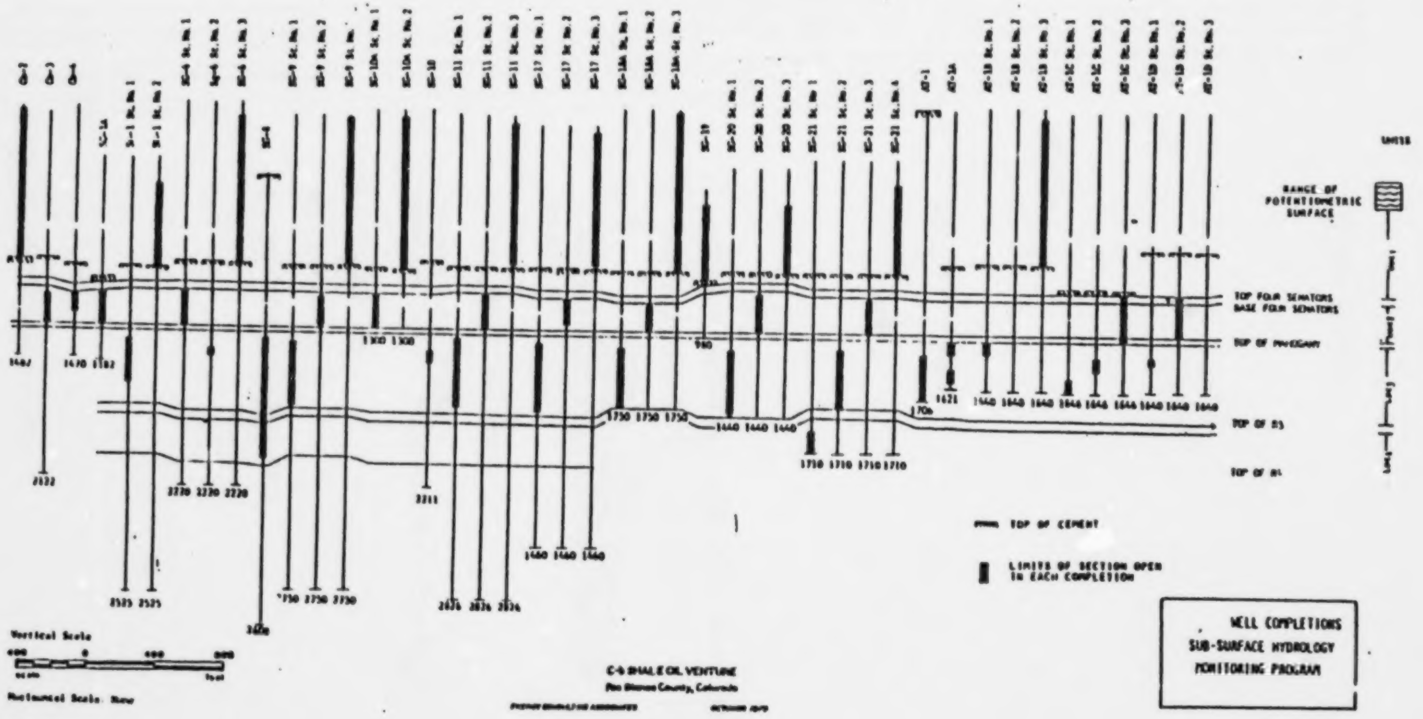


Fig. 108 (Cb Shale Oil Project, 1978, Reinjection Application Permit, prepared by ECA Associates)

Figure 108

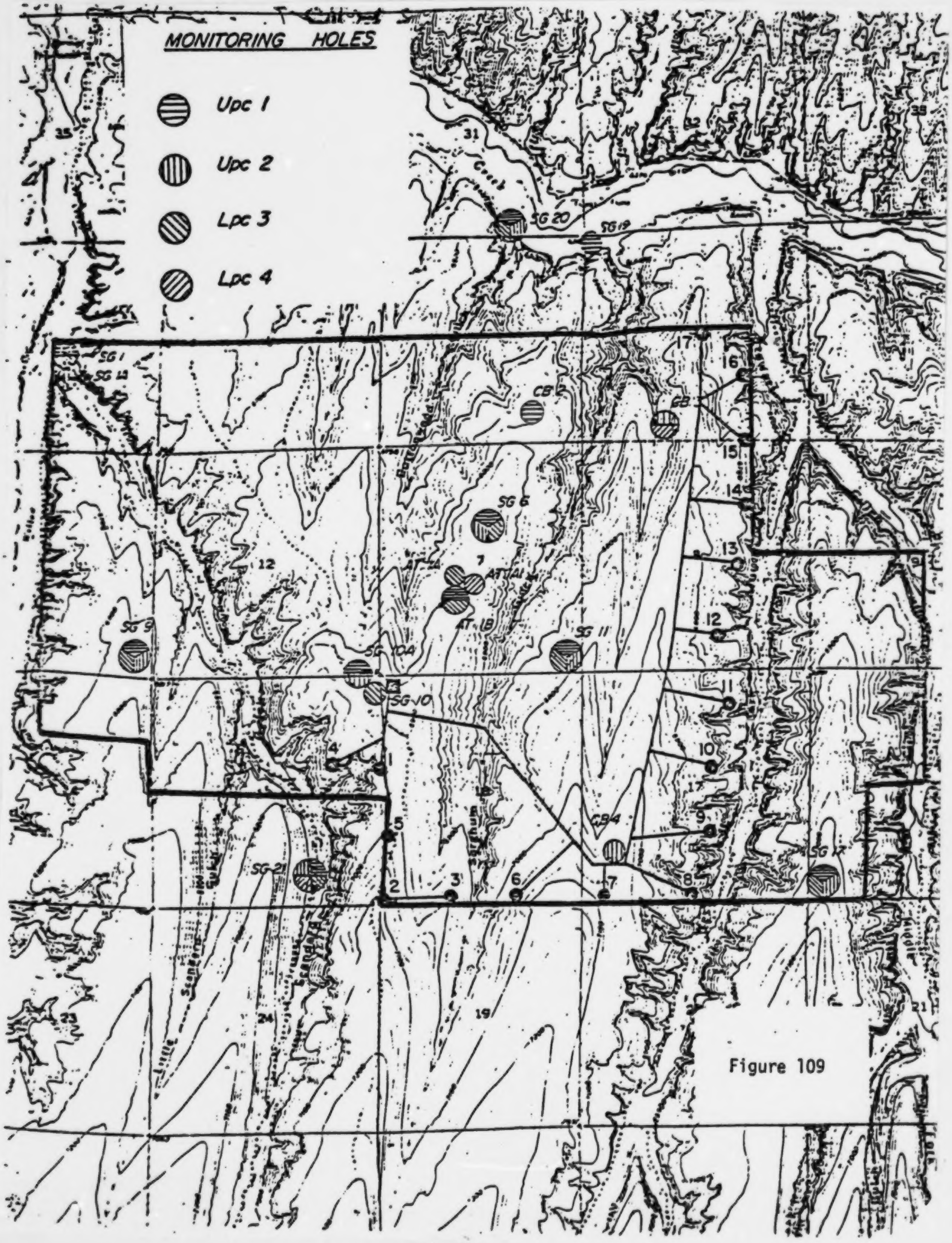
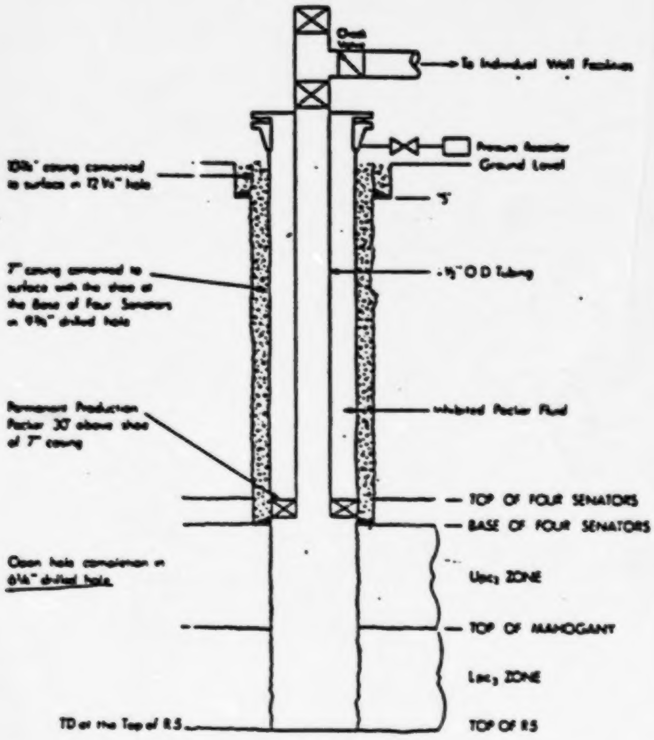

MONITORING HOLES
Upc 1
Upc 2
Lpc 3
Lpc 4
SG 20
SG 19
SG 1
SG 13
CB
CB
SG 6
AT 2A
AT 1A
AT 1B
SG 9
SG 10A
SG 10
SG 11
CB 4
SG 21
SG 17
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

Figure 109

SCHEMATIC OF INJECTION WELLS


Check Valve
To Individual Well Facilities
Pressure Recorder
Ground Level
10¾" casing cemented to surface in 12¼" hole
5'
7" casing cemented to surface with the shoe at the Base of Four Senators in 9⅞" drilled hole
2⅞" O D Tubing
Permanent Production Packer 30' above shoe of 7" casing
Inhibited Packer Fluid
TOP OF FOUR SENATORS
BASE OF FOUR SENATORS
Open hole completion in 6¼" drilled hole
Uac3 ZONE
TOP OF MAHOGANY
Lac3 ZONE
TD at the Top of R5
TOP OF R5

DEPTHS FOR INDIVIDUAL WELLS

	Injection Well Name	Ground Level Elevation (Feet above Sea Level)	Top of Four Senators (Feet)	Base of Four Senators 7" Casing Point (Feet)	Top of Mahogany (Feet)	Top of R5 TD of Well (Feet)	Maximum Injection Pressure* (PSI)	Limit of System** (PSI)	Location Description
PHASE I	WI - 1	6950	1000	1040	1240	1710	330	589	2150' FNL and 100' FEL Sec 13,T3S-R97W
	WI - 2	7080	1030	1070	1270	1740	339	606	220' FSL and 100' FWL Sec 18,T3S-R96W
	WI - 3	6980	930	970	1170	1640	307	550	300' FSL and 1610' FWL Sec 18,T3S R96W
	WI - 4	6910	960	1000	1200	1670	317	567	2000' FNL and 1280' FEL Sec 13,T3S R97W
	WI - 5	7010	1020	1060	1260	1730	336	600	1650' FSL and 100' FWL Sec 18,T3S-R96W
PHASE II	WI - 6	7060	1020	1060	1260	1730	336	600	180' FSL and 1430' FEL Sec 18,T3S-R96W
	WI - 7	7085	1055	1095	1295	1765	347	620	160' FSL and 550' FWL Sec 17,T3S-R96W
	WI - 8	6870	850	890	1090	1560	282	504	140' FSL and 2550' FWL Sec 17,T3S-R96W
	WI - 9	6840	850	890	1090	1560	282	504	1600' FSL and 2200' FEL Sec 17,T3S-R96W
	WI - 10	6810	855	895	1095	1565	284	507	2250' FNL and 2200' FEL Sec 17,T3S-R96W
PHASE III (If Required)	WI - 11	6780	865	905	1105	1575	287	513	750' FNL and 1850' FEL Sec 17 T3S-R96W
	WI - 12	6740	890	930	1130	1600	295	527	900' FSL and [illegible] FEL Sec 8,T3S-R96W
	WI - 13	6740	930	970	1170	1640	307	550	2500' FSL and 1700' FEL Sec 8 T3S-R96W
	WI - 14	6690	915	955	1155	1625	303	541	1450' FNL and 1450' FEL Sec 8 T3S-R96W
	WI - 15	6700	950	990	1190	1660	314	561	100' FSL and 1500' FEL Sec 5,T3S-R96W
	WI - 16	6600	880	920	1120	1590	292	521	1550' FSL and 1500' FEL Sec 5,T3S-R96W
	WI - 17	6700	1015	1055	1255	1725	334	598	2550' FSL and 2450' FEL Sec 5,T3S-R96W

* Based on .75 psi/ft of depth at the Base of Four Senators

** Based on 1.0 psi/ft of depth at the Base of Four Senators

(Cb Shale Oil Project, 1978, Reinjection Application Permit, prepared by ECA Associates)

Figure 110

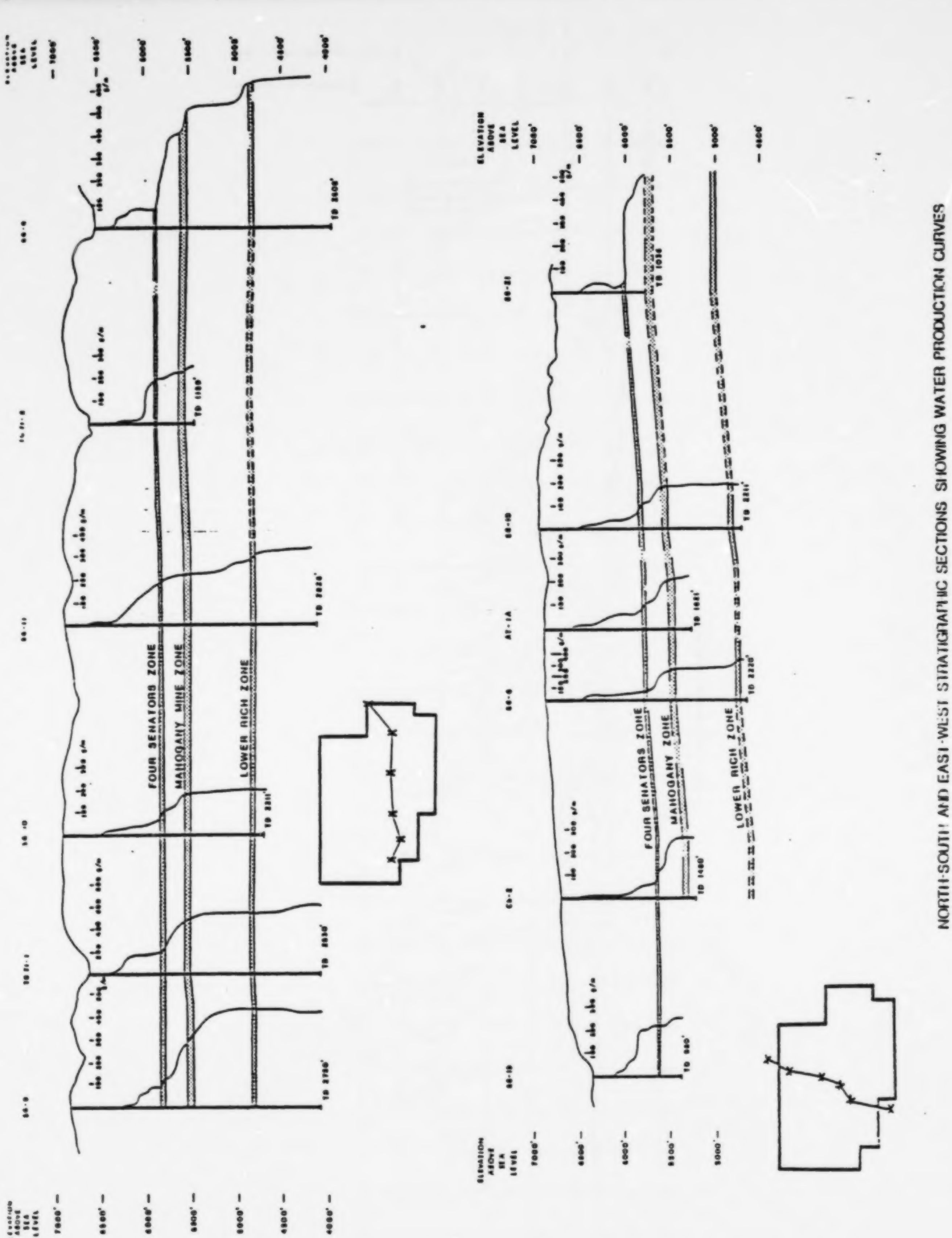


Figure 111

(Cb Shale Oil Venture, 1976, Enviromental Baseline Program, Volume II, Final Report, Hydrology)

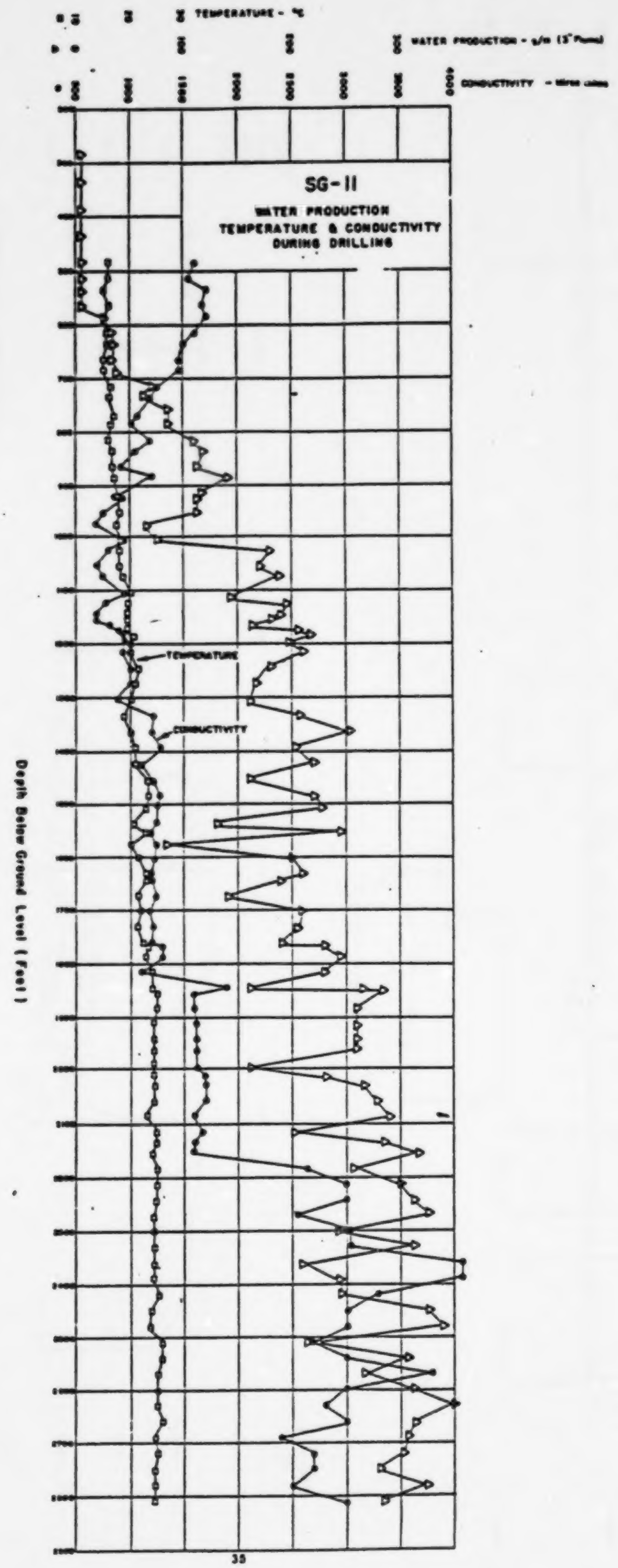
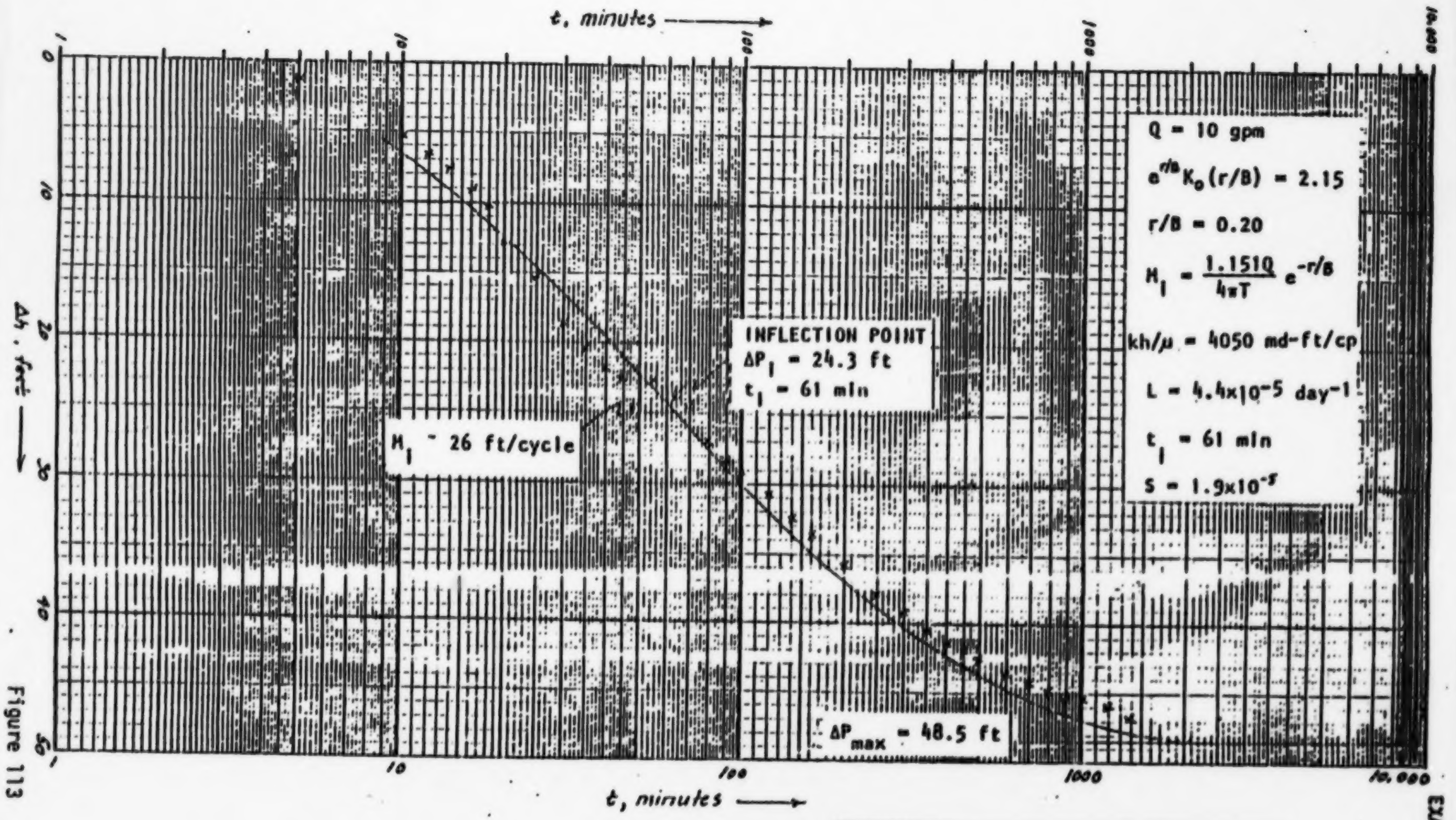


Fig. 112 (Cb Shale Oil Venture, 1974, Summary Quarterly Reports #1 through #9)

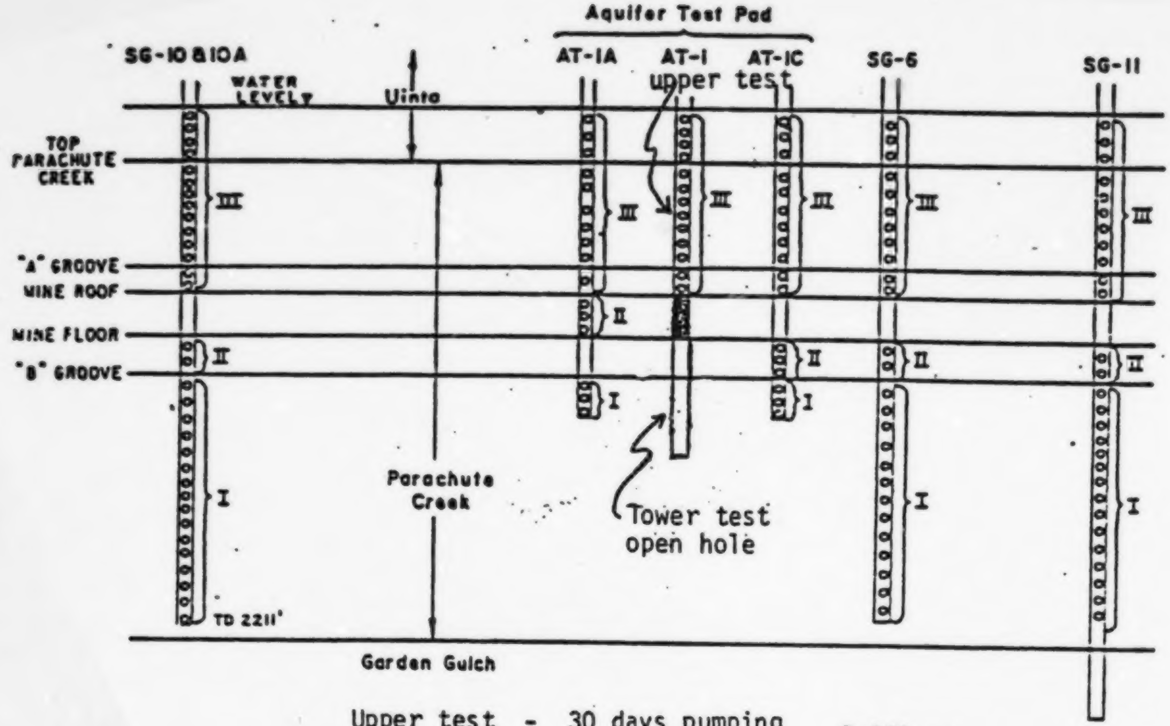
EXAMPLE 3



MINIPUMP TEST No.10 - DRAWDOWN PORTION

(Cb Shale Oil Project, 1978, Reinjection Application Permit, prepared by ECA Associates.)

Figure 113



Upper test - 30 days pumping
5 days recovery Q=365 gpm

Lower test - 18 days pumping Q=120 gpm
8 days recovery

Perforated Interval

} II Tubing String Number

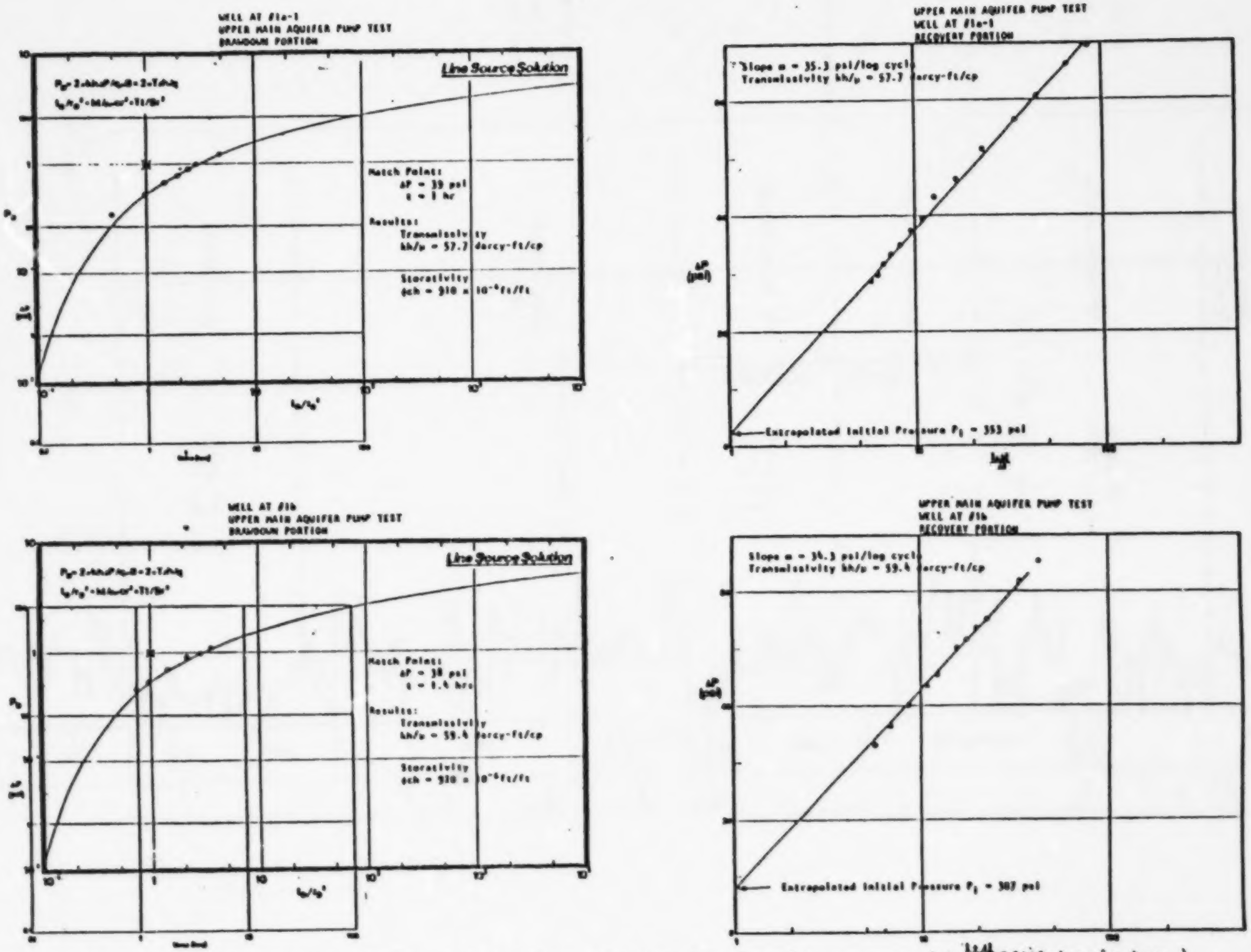
SCHEMATIC CROSS-SECTION
AQUIFER PUMP TEST

C-b TRACT, COLORADO

SCALE: None

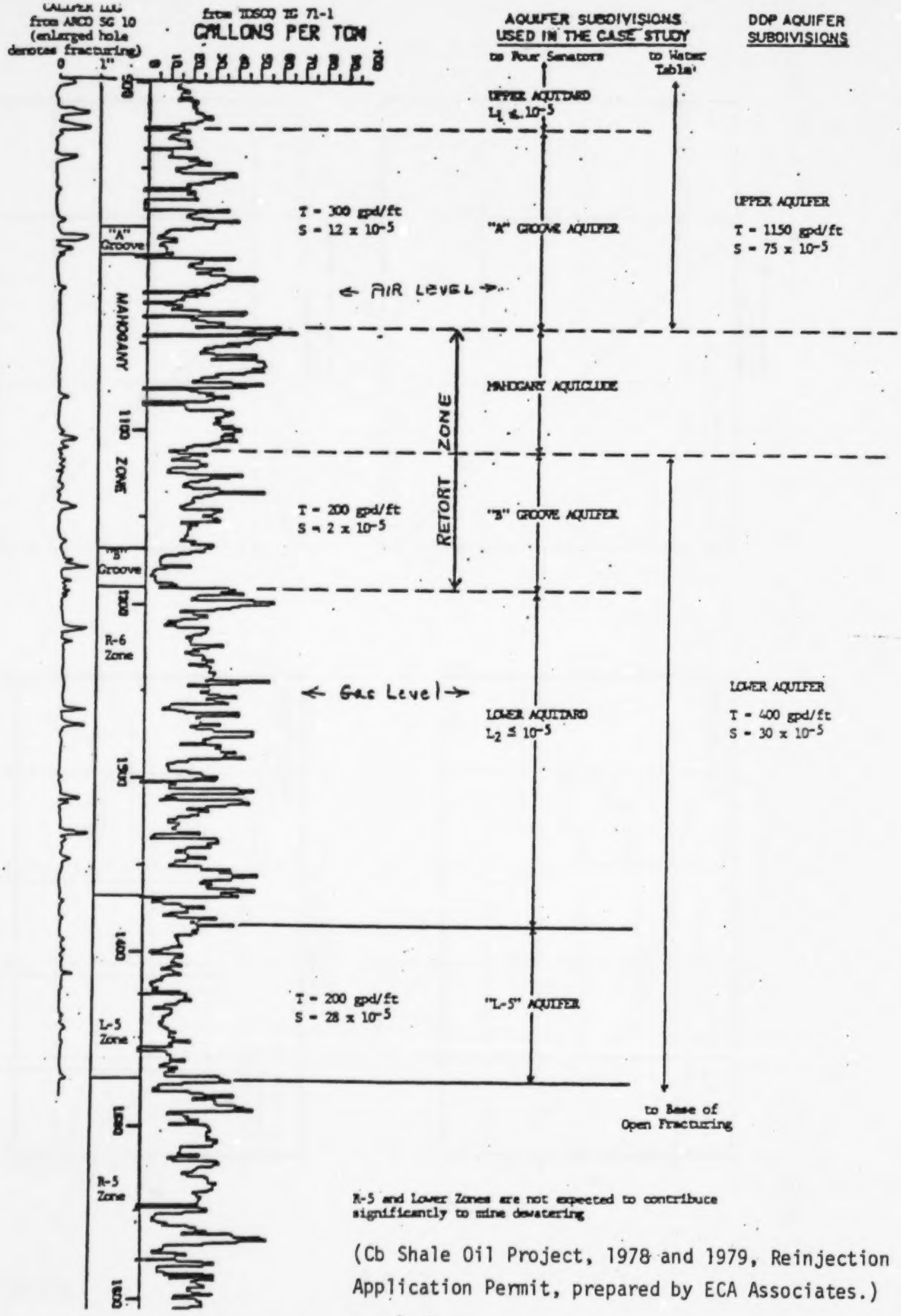
(Cb Shale Oil Venture, 1976, Environmental Baseline Program, Volume II, Final Report, Hydrology.)

Figure 114



(Cb Shale Oil Project, 1978, Reinjection Application Permit, prepared by ECA Associa tes.)

Figure 115



(Cb Shale Oil Project, 1978 and 1979, Reinjection Application Permit, prepared by ECA Associates.)

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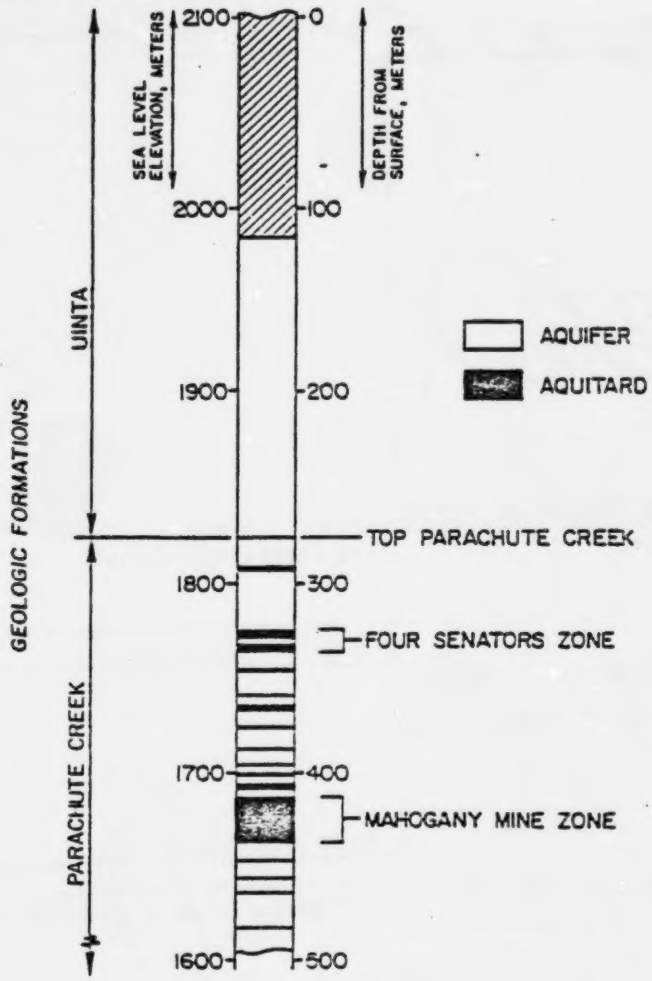
Figure 116

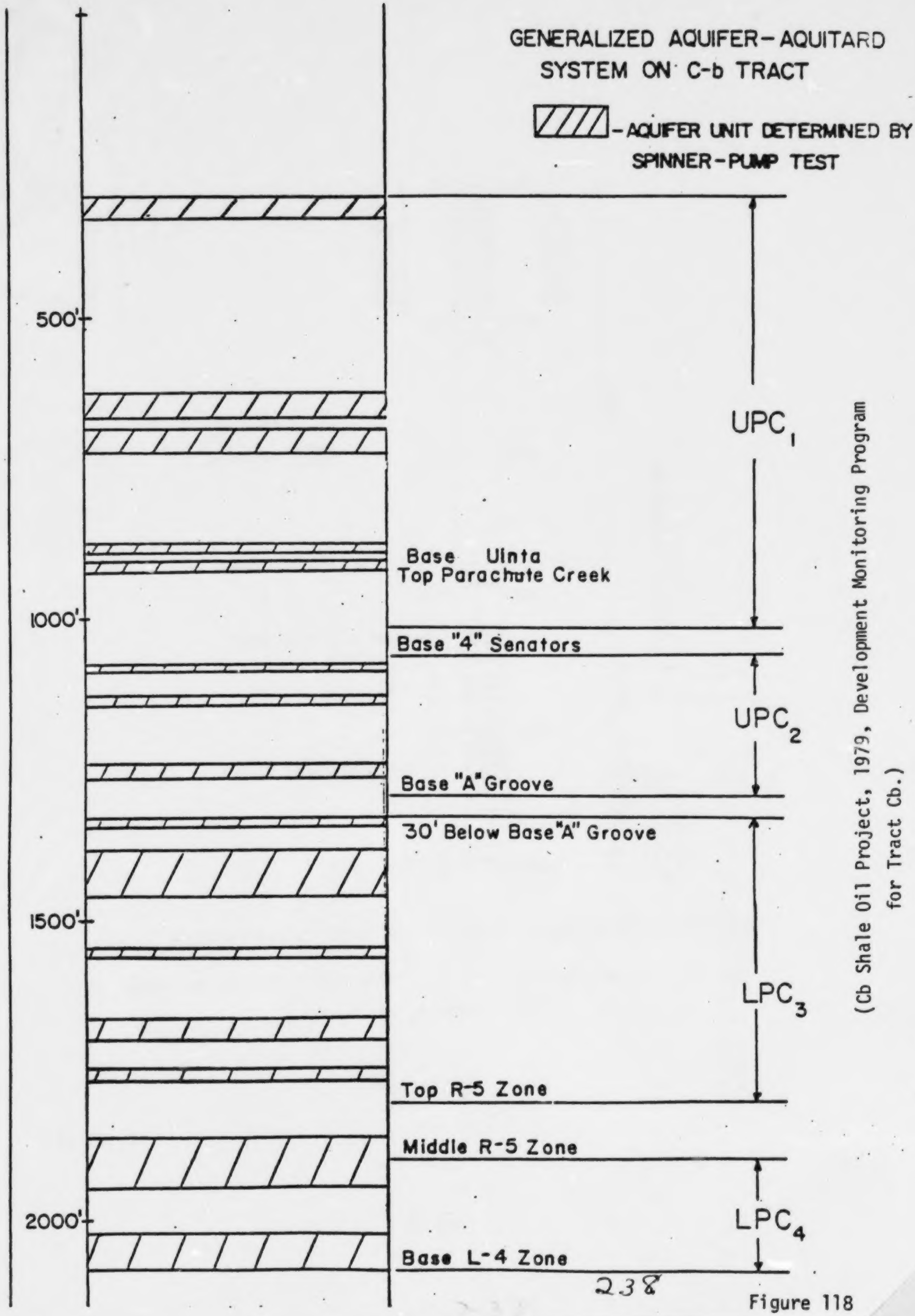


SECTION SHOWING AQUIFERS AND AQUITARDS

(Cb Shale Oil Venture, 1976, Environmental Baseline program, Volume II, Final Report, Hydrology.)

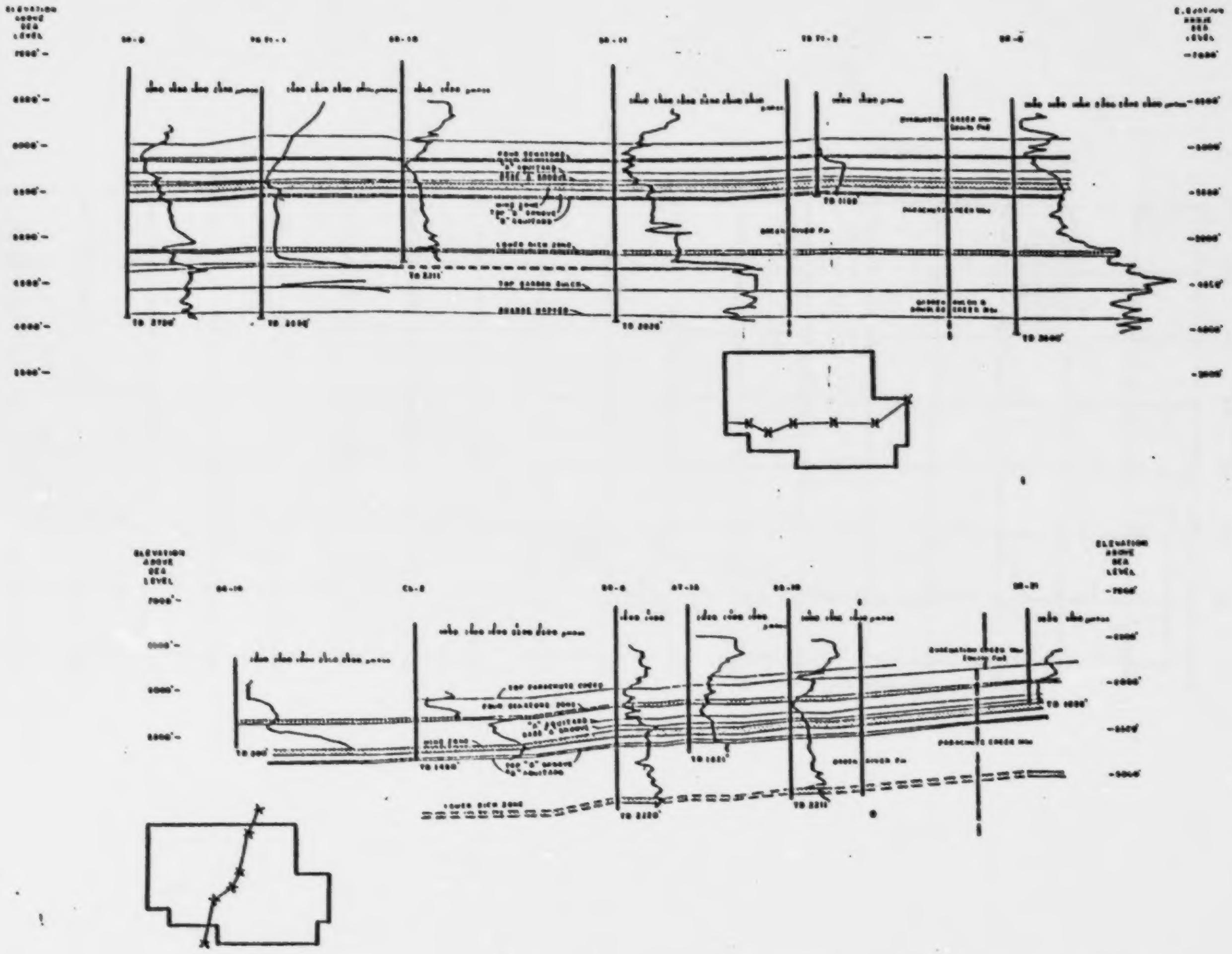
Figure 117

GENERALIZED AQUIFER-AQUITARD SYSTEM ON C-b TRACT



(Cb Shale Oil Project, 1979, Development Monitoring Program for Tract Cb.)

Figure 118



NORTH-SOUTH AND EAST-WEST STRATIGRAPHIC SECTIONS SHOWING WATER CONDUCTANCE CURVES

(Cb Shale Oil Venture, 1976, Environmental Baseline Program,
Volume II, Final Report, Hydrology.)

Figure 119

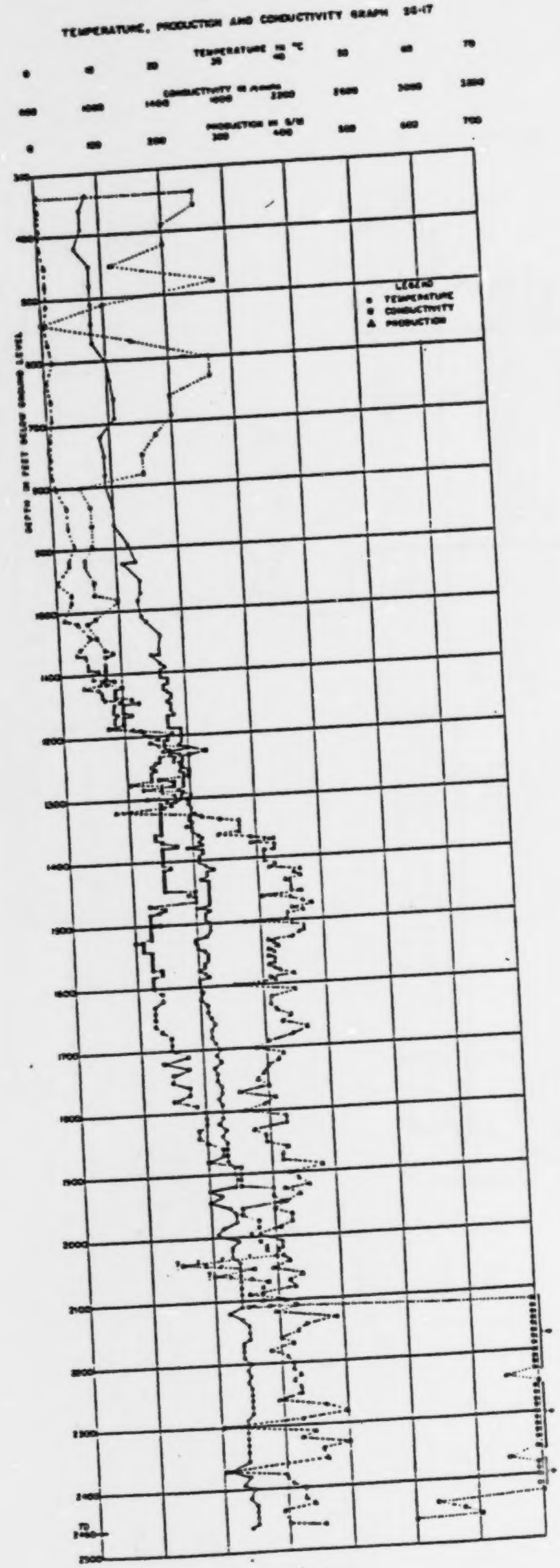

TEMPERATURE, PRODUCTION AND CONDUCTIVITY GRAPH 16-17
TEMPERATURE IN °C
0
10
20
30
40
50
60
70
CONDUCTIVITY IN µmhos
600
1000
1400
1800
2200
2600
3000
3400
PRODUCTION IN G/M
0
100
200
300
400
500
600
700
DEPTH IN FEET BELOW GROUND LEVEL
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
TD 2460
2500
LEGEND
● TEMPERATURE
● CONDUCTIVITY
▲ PRODUCTION

Figure 120

TEMPERATURE, PRODUCTION AND CONDUCTIVITY GRAPH SB-1

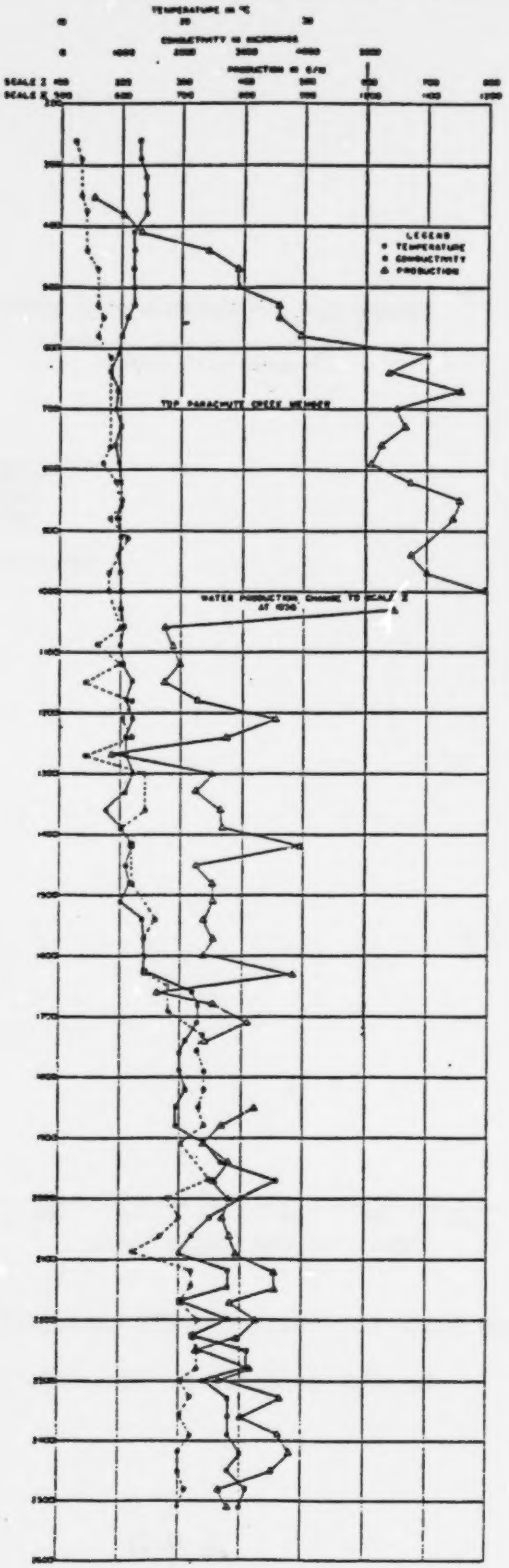


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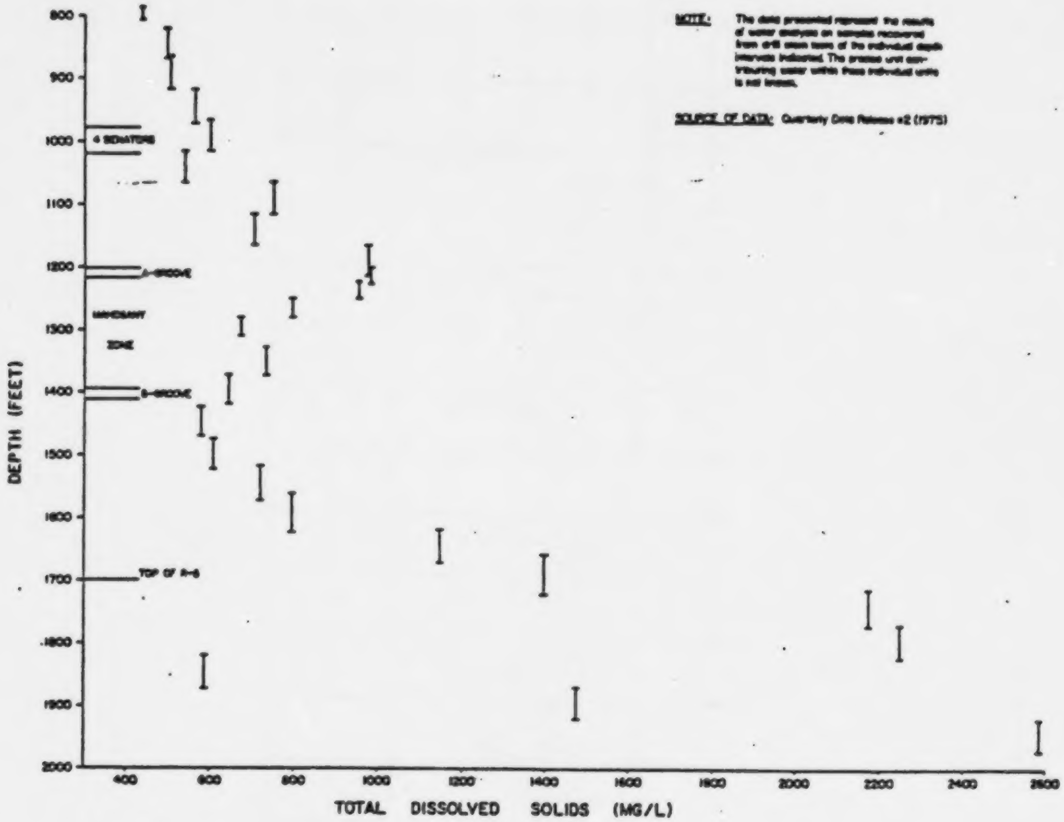
Figure 121

WATER QUALITY VARIATION WITH DEPTH

WELL SG-17 SW SW Sec.16 T3S R96W

RIO BLANCO COUNTY, COLORADO



NOTE: The data presented represent the results of water analyses on samples recovered from drill stem tests of the individual depth intervals indicated. The precise unit contributing water within these individual units is not known.

SOURCE OF DATA: Quarterly Data Release #2 (1975)

(Cb Shale Oil Project, 1978, Reinjection Application Permit, prepared by ECA Associates.)

Figure 122

Tract Cb

Well 33x-1

(Cb Shale Oil Project,
1981, Well recompletion
report, unpublished, in
AOSO, Grand Jct.)

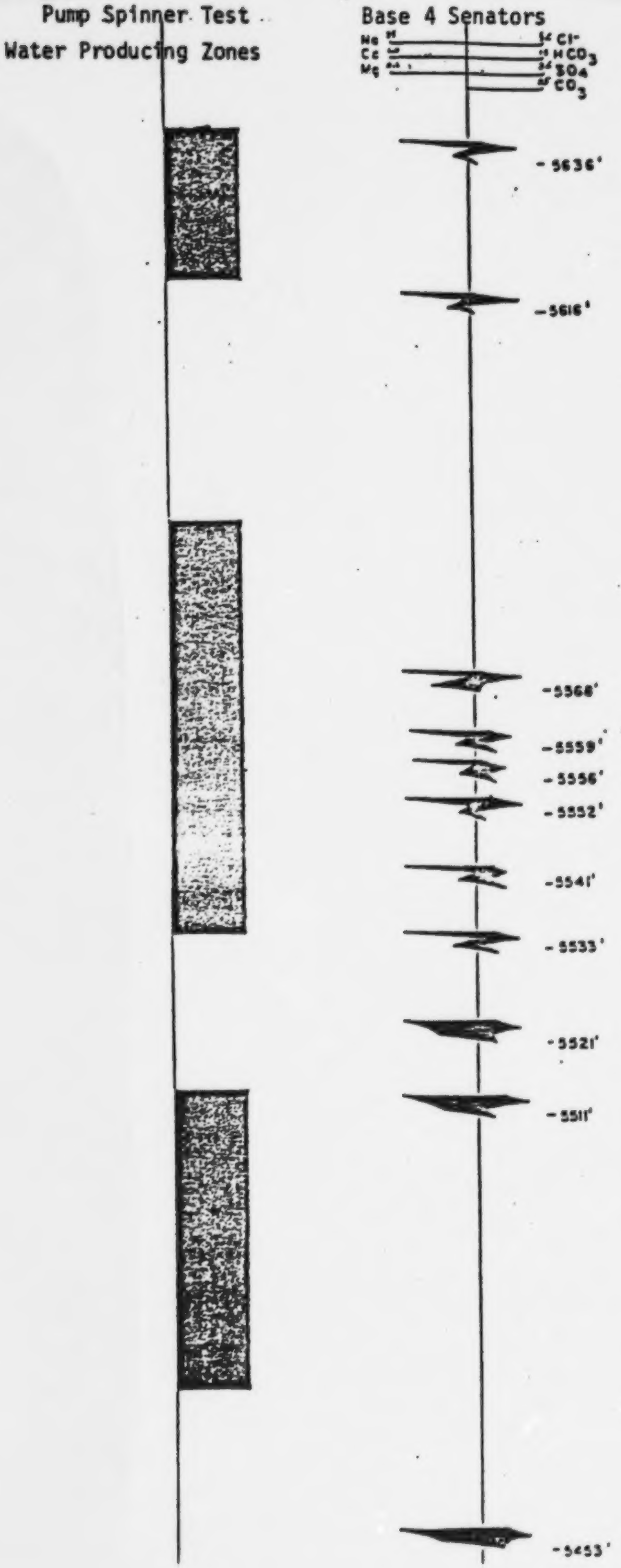
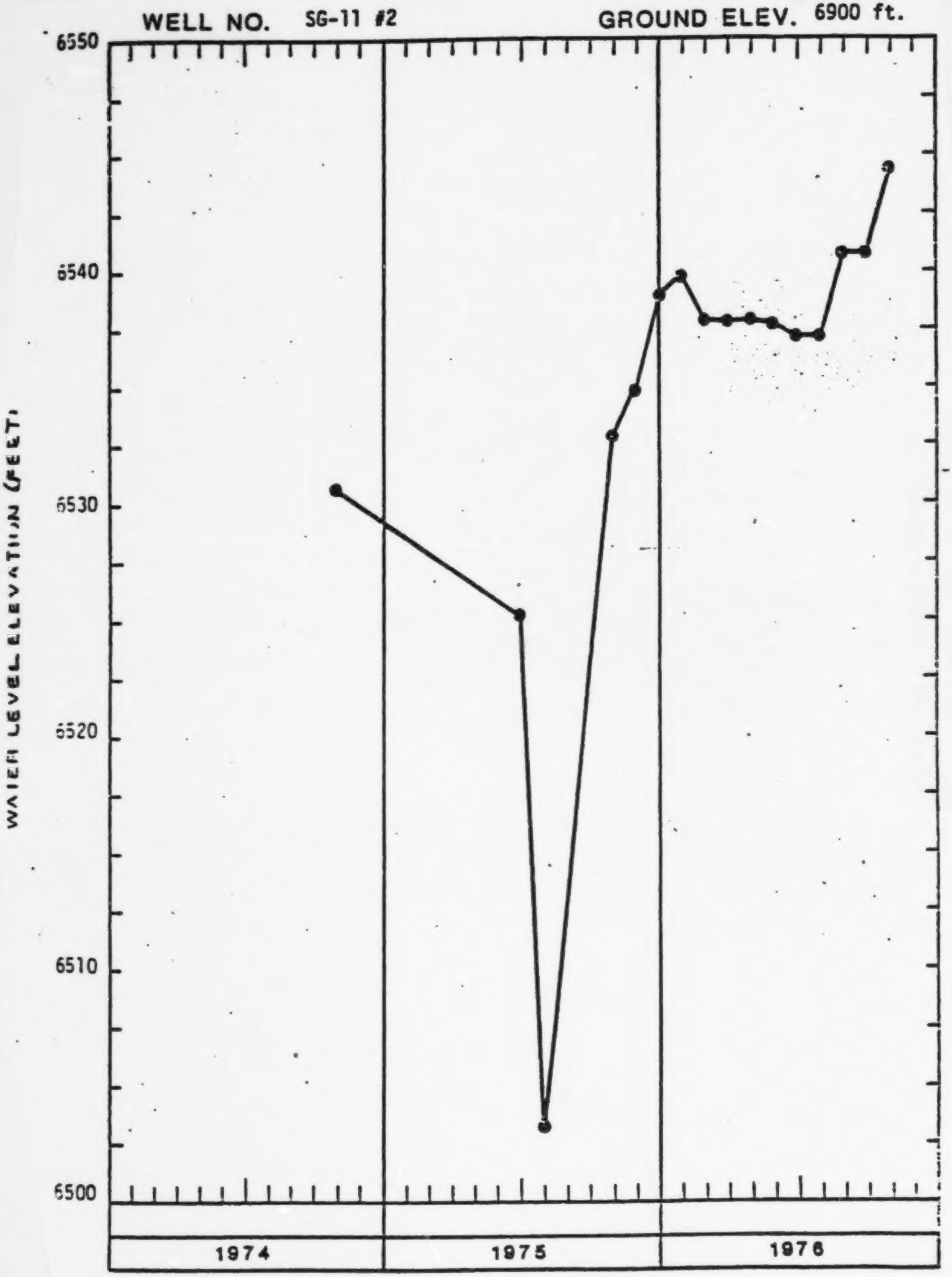


Figure 123

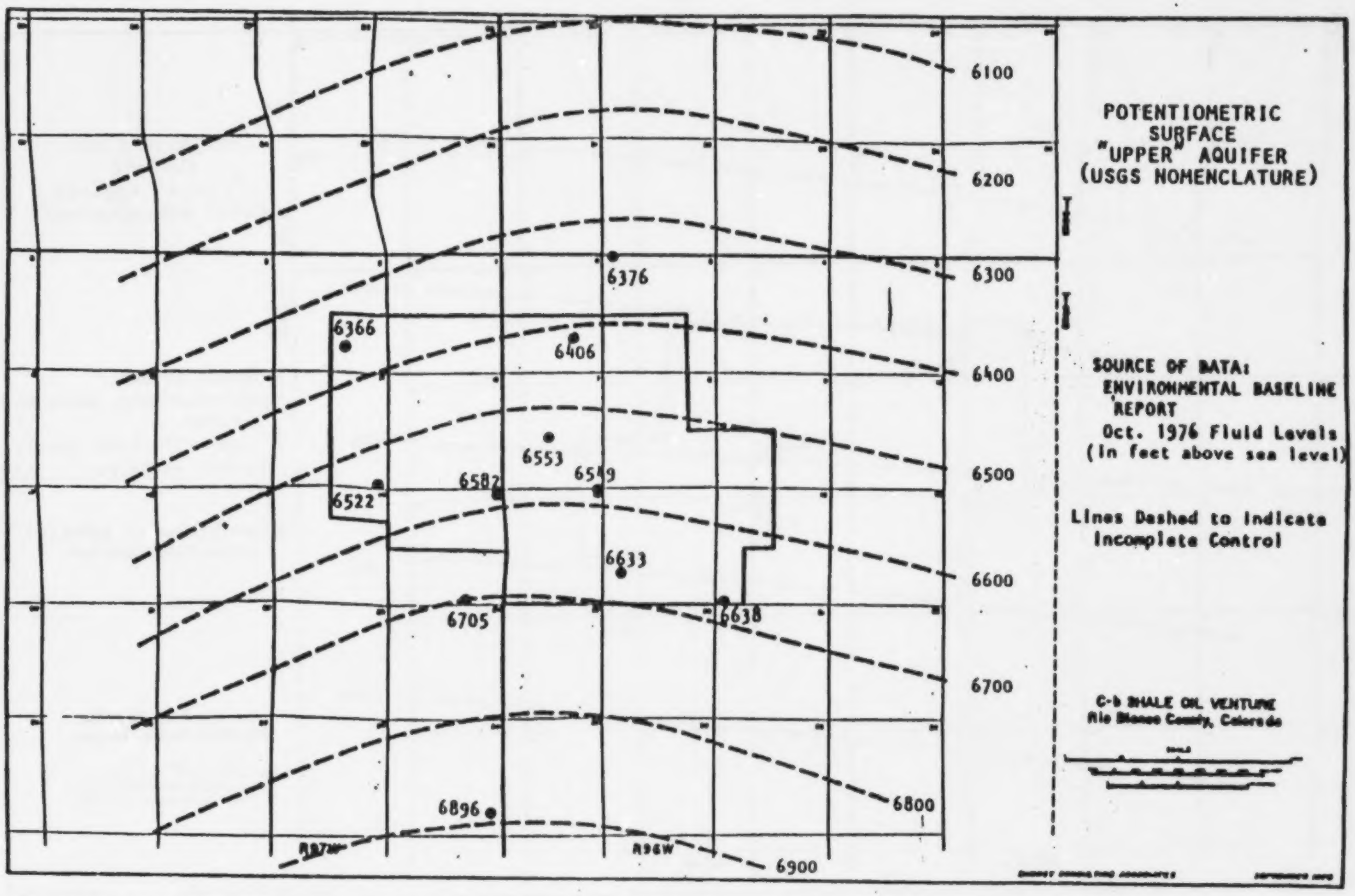


WATER LEVEL DATA

·244

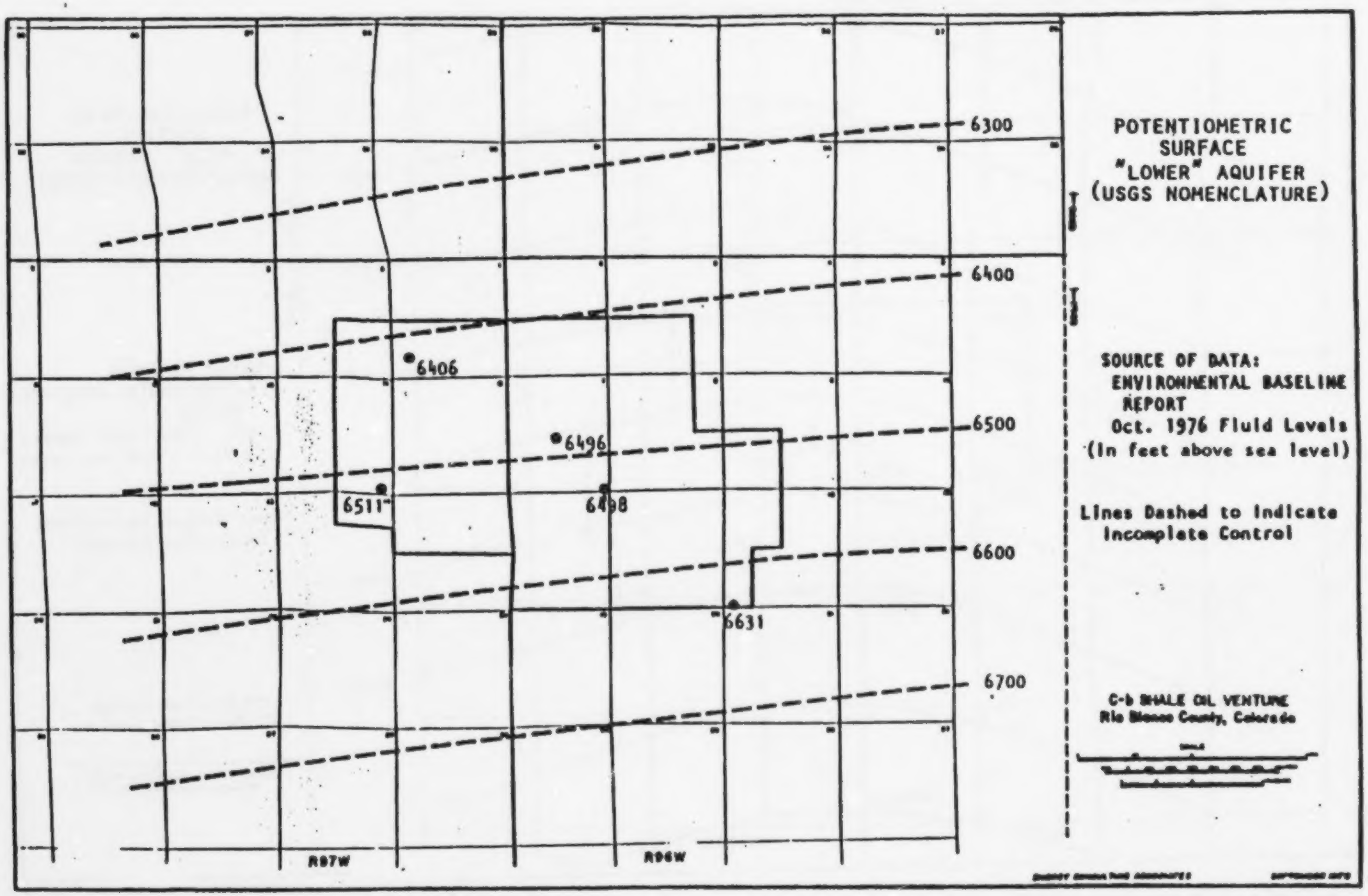
(Cb Shale Oil Venture, 1976, Environmental Baseline Program, Volume II, Final Report, Hydrology.)

Figure 124


POTENTIOMETRIC SURFACE "UPPER" AQUIFER (USGS NOMENCLATURE)
SOURCE OF DATA: ENVIRONMENTAL BASELINE REPORT
Oct. 1976 Fluid Levels (In feet above sea level)
Lines Dashed to Indicate Incomplete Control
C-b SHALE OIL VENTURE
Rio Blanco County, Colorado
6100
6200
6300
6400
6500
6600
6700
6800
6900
6376
6366
6406
6553
6522
6582
6549
6633
6705
6638
6896
R97W
R96W

(Cb Shale Oil Project, 1978, Reinjection Application Permit, prepared by ECA Associates.)

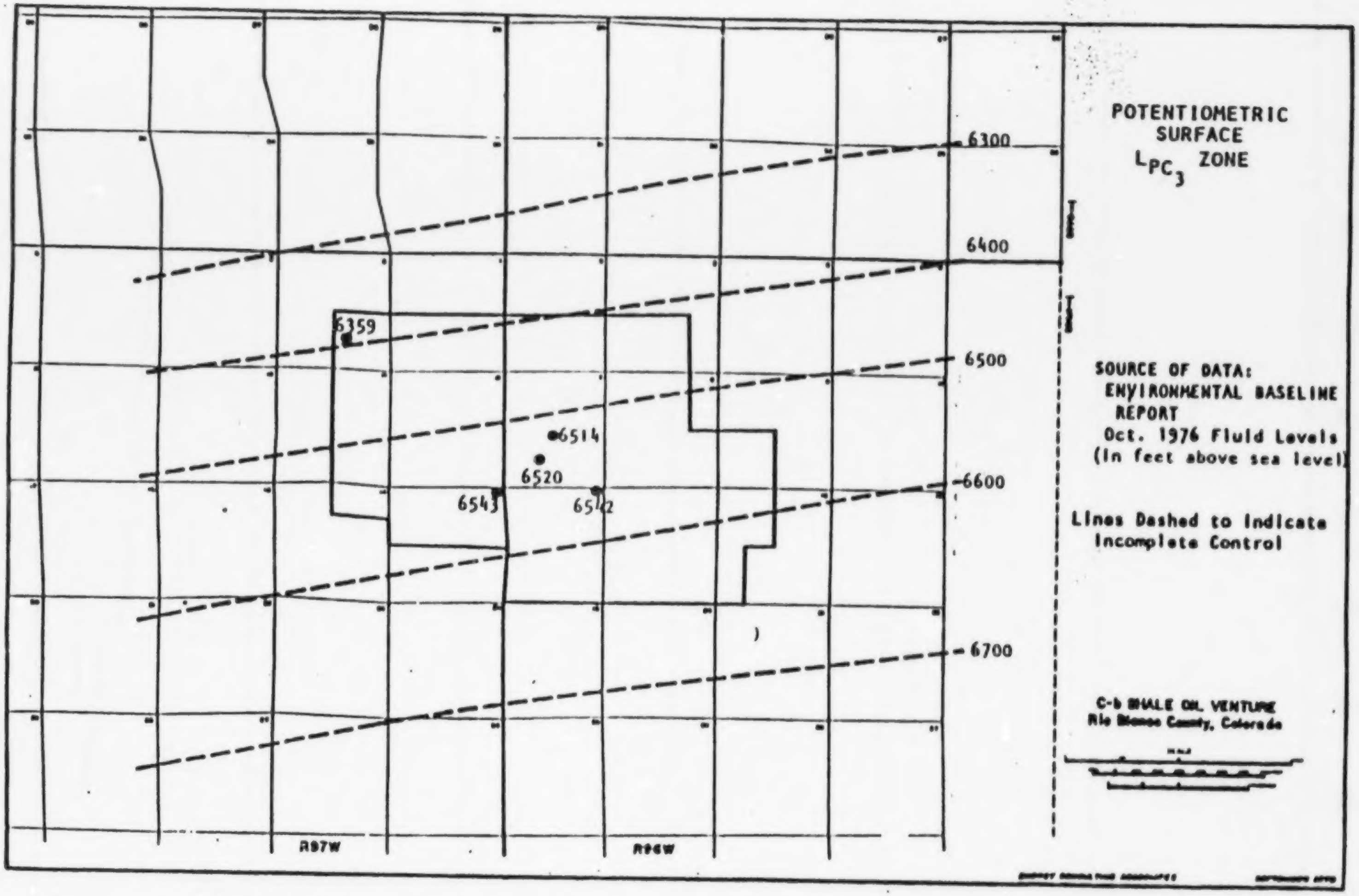
Figure 125



(Cb Shale Oil Project, 1978, Reinjection Application Permit, prepared by ECA Associates.)

Figure 126

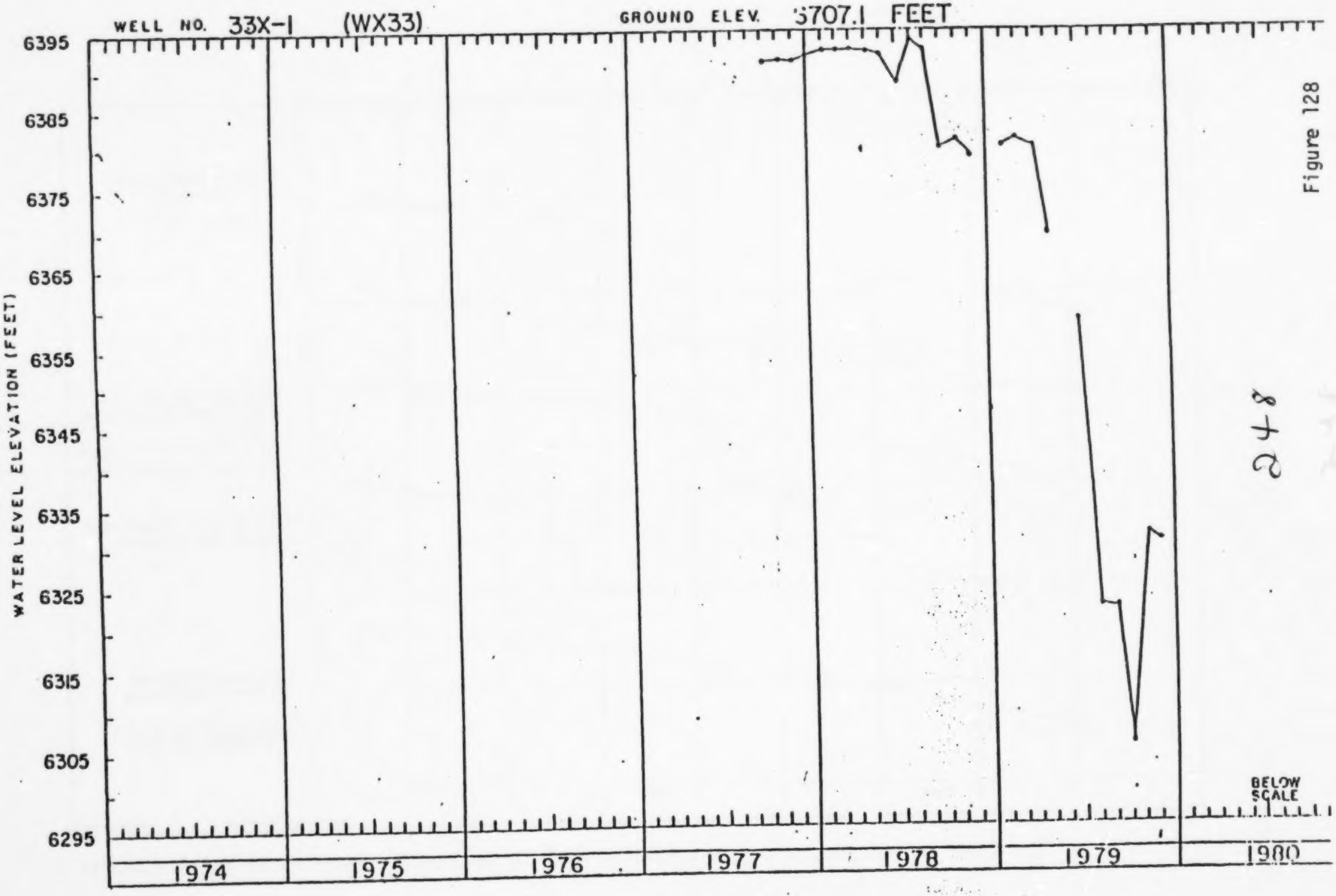
Figure 126



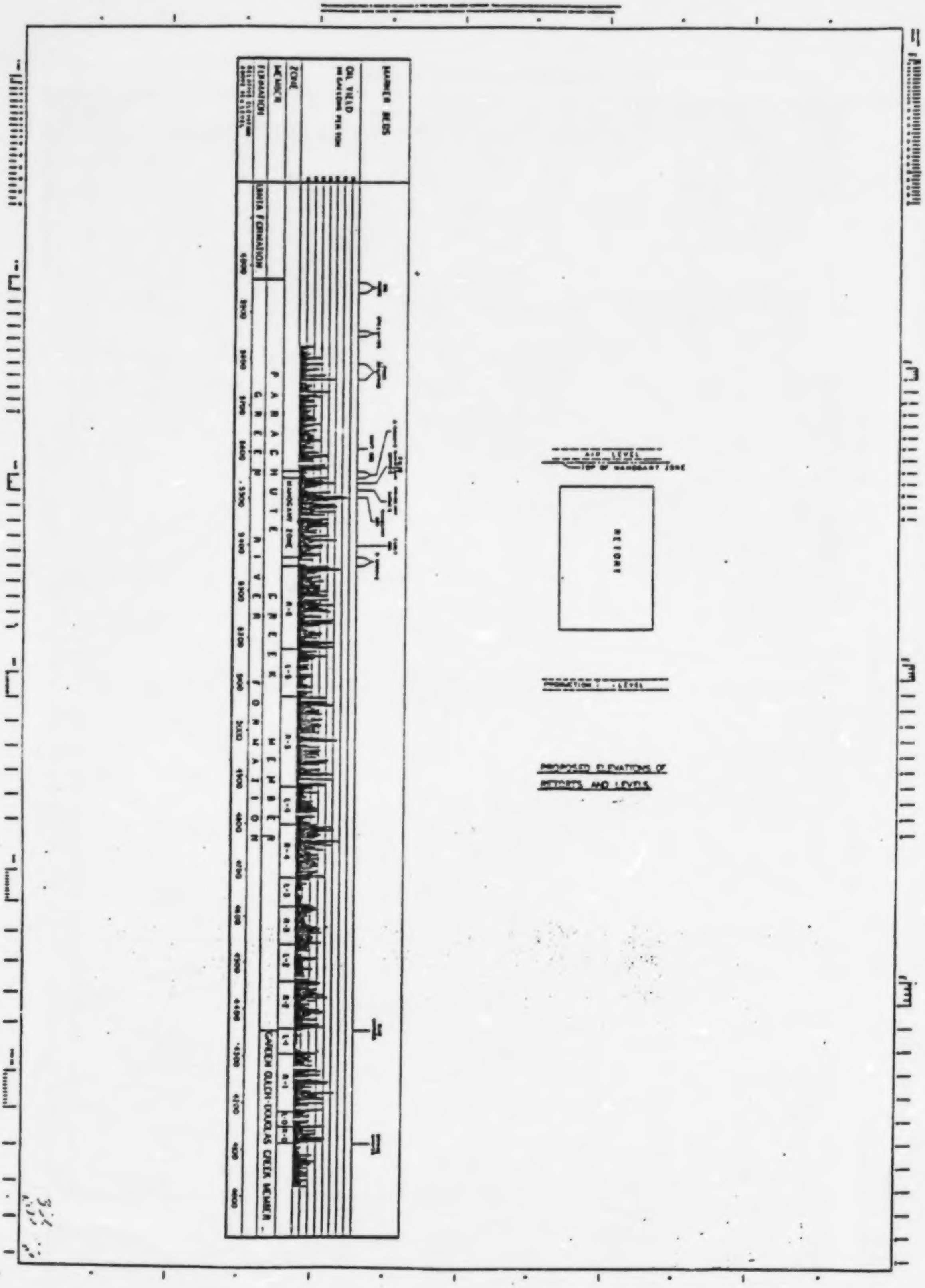
(Cb Shale Oil Project, 1978, Reinjection Application Permit, prepared by ECA Associates.)

Figure 127

Figure 128



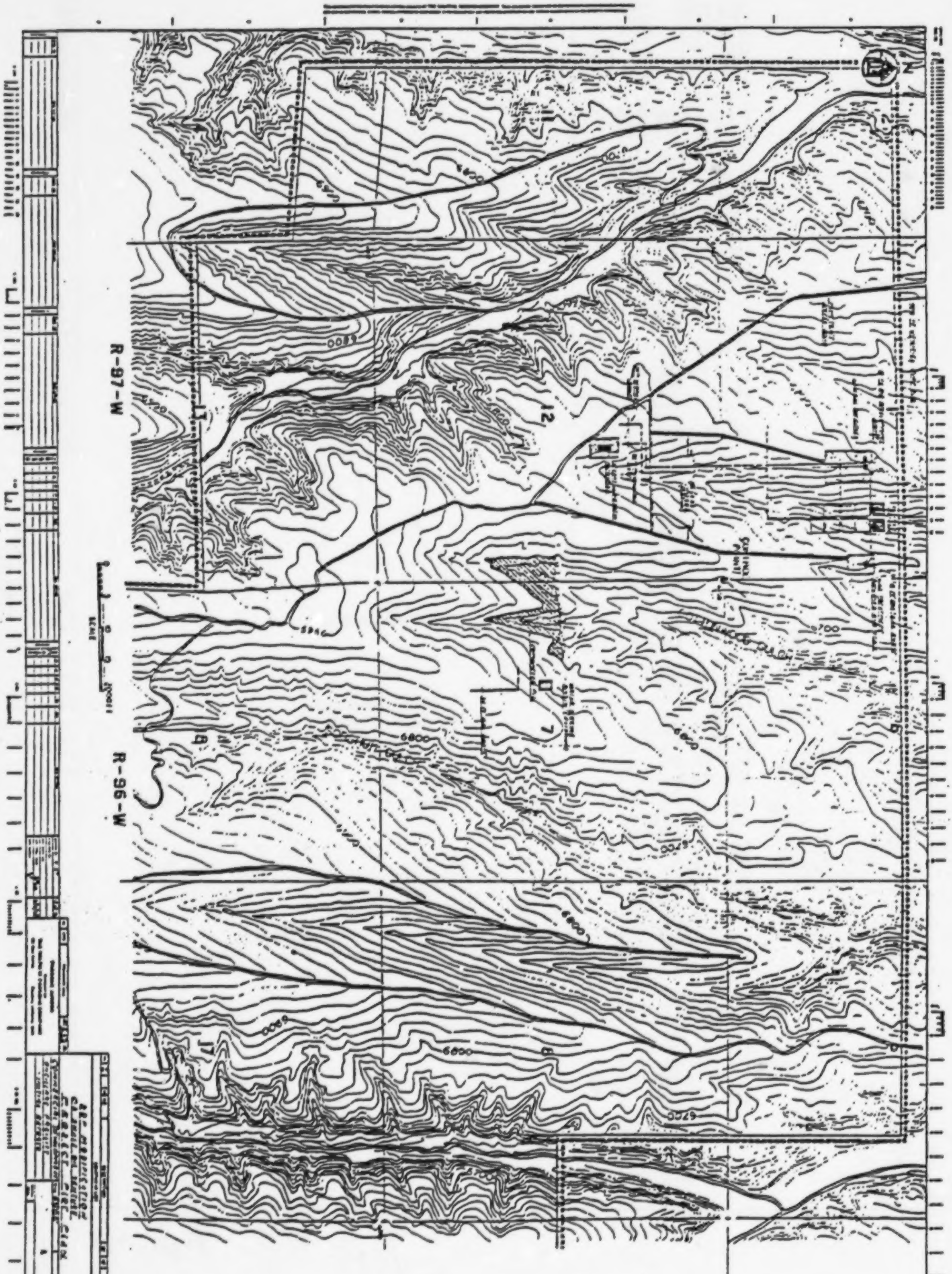
WATER LEVEL DATA
(Cb Shale Oil Project, 1979, Development Monitoring Program for Tract Cb.)
Figure 128



Retort Elevation/Stratigraphic Section

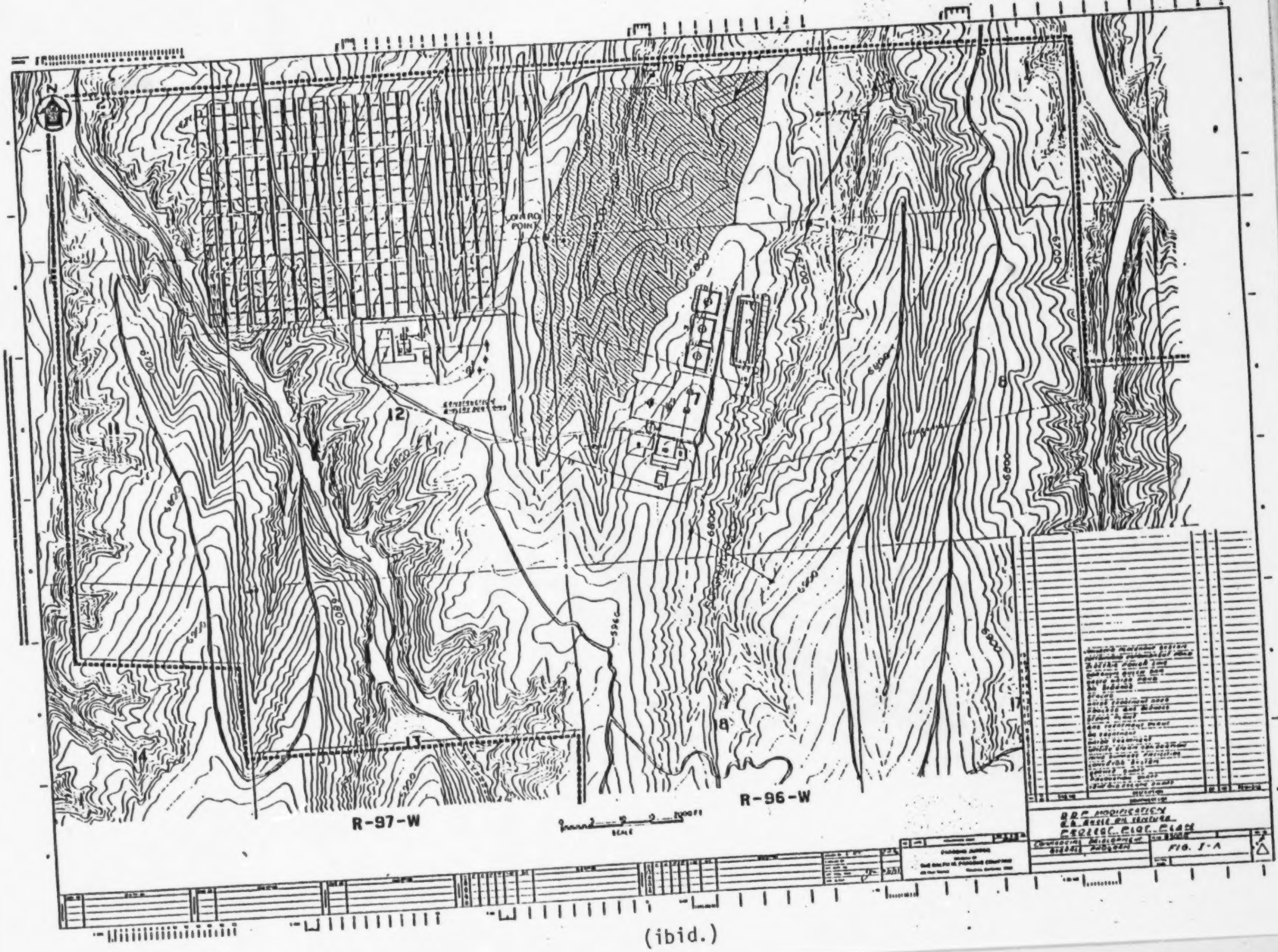
(ibid.)

Figure 129



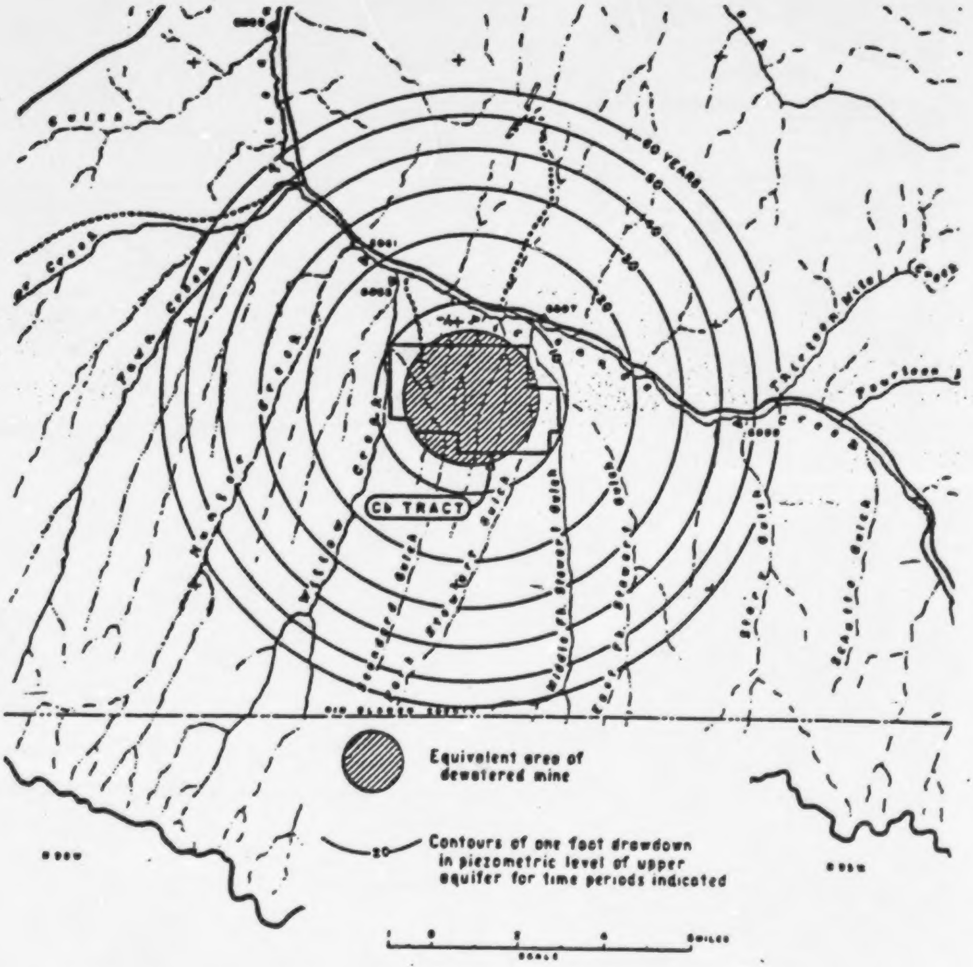
(Cb Shale Oil Project, 1979, Development Monitoring Program for Tract Cb.)

Figure 130



(ibid.)

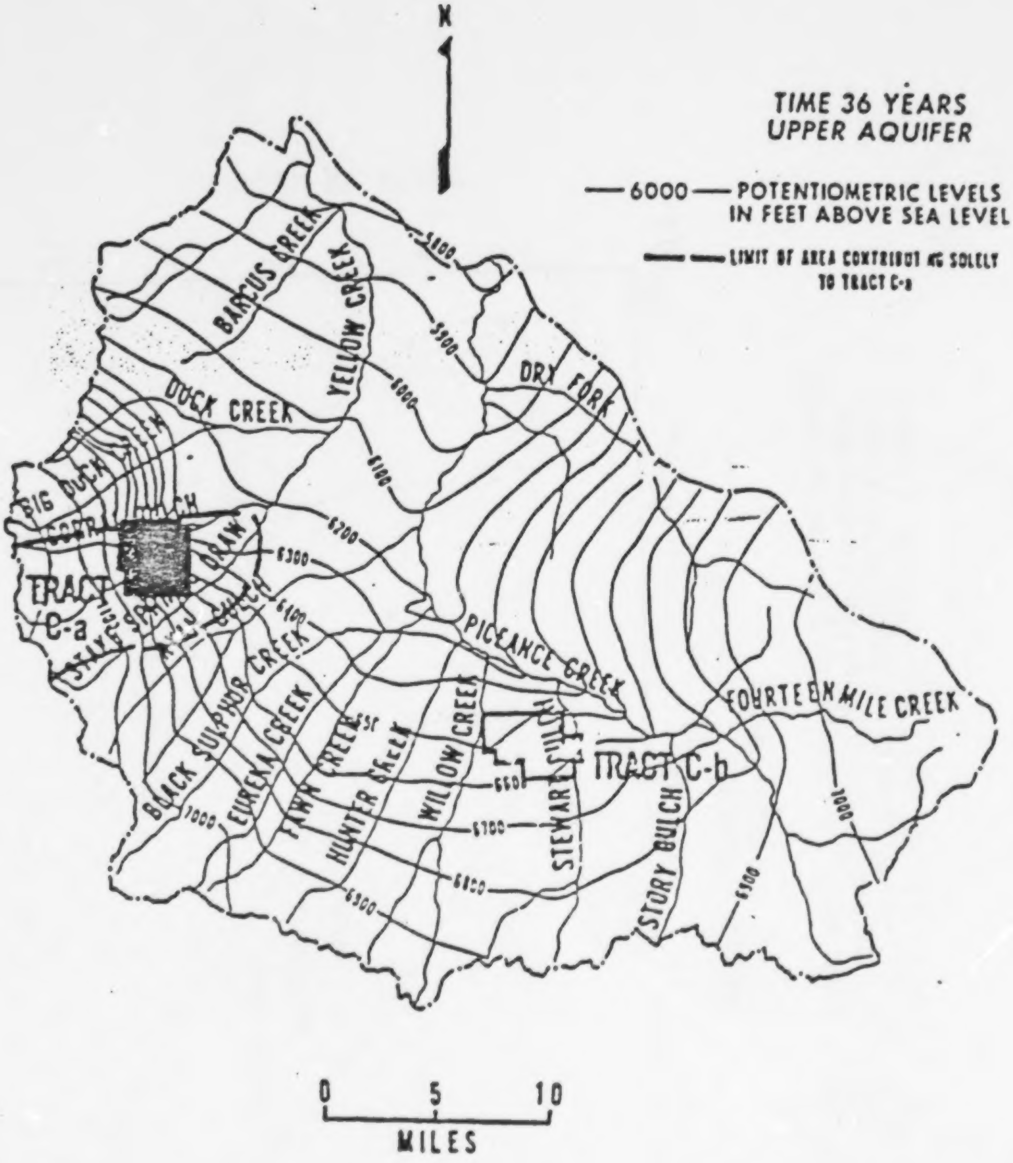
Figure 131


60 YEARS
50
40
30
20
Cb TRACT
Equivalent area of dewatered mine
20
Contours of one foot drawdown in piezometric level of upper aquifer for time periods indicated
MILES
SCALE

Map showing predictions of shape and extent of cone of depression due to dewatering of tract Cb for in-situ mining. From Tipton and Kalmbach, 1977.

252

Figure 132



Map showing effect of dewatering of tract Ca on shape of piezometric surface in the Piceance Creek basin as predicted by computer model. From Rio Blanco Oil Shale Project, 1976.

253

Figure 133

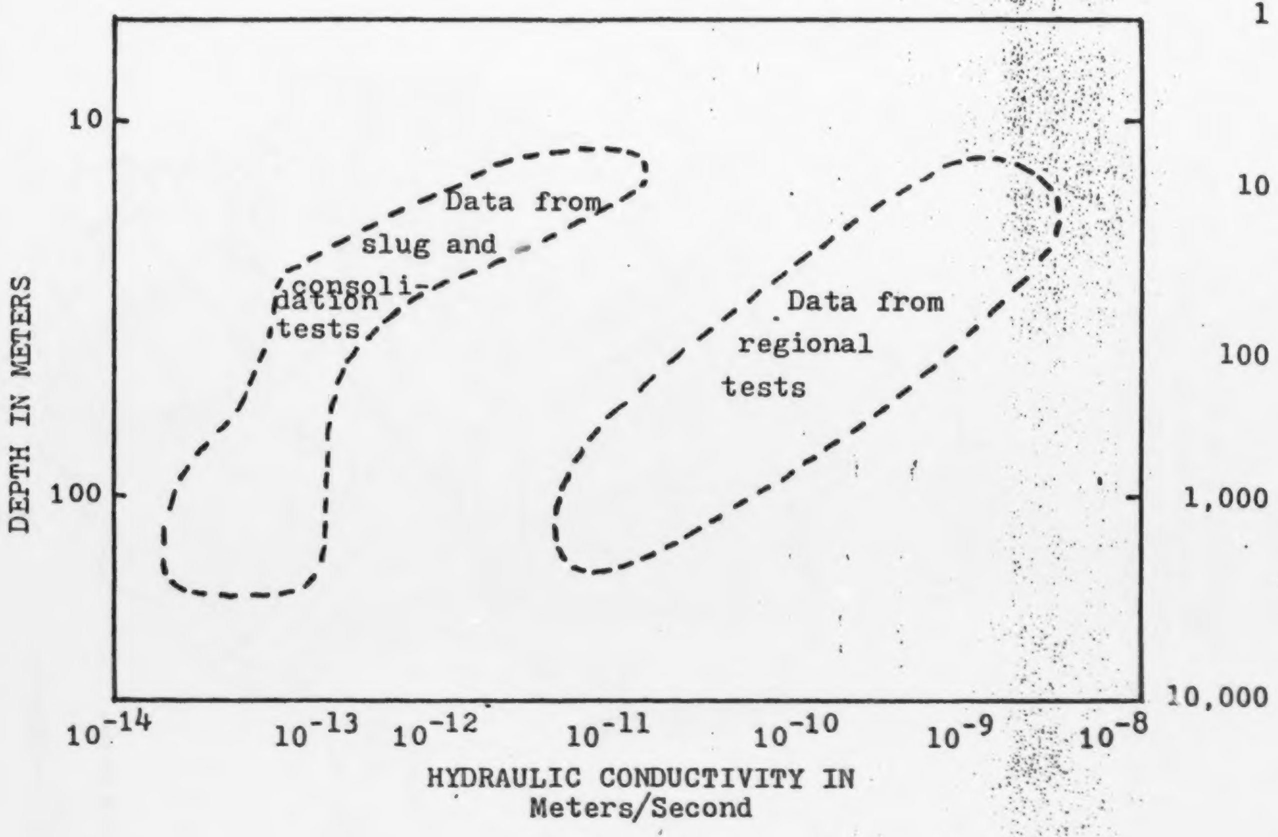


Diagram showing groupings of data from local (slug and consolidation) tests and regional model values of hydraulic conductivity in the Pierre shale. Generalized from Neuzil, 1980, p.37.

Figure 134 NEUZIL, 1980

Figure 134

FIGURE 135 IN POCKET

SECTION 2
MINERALOGY FIGURES

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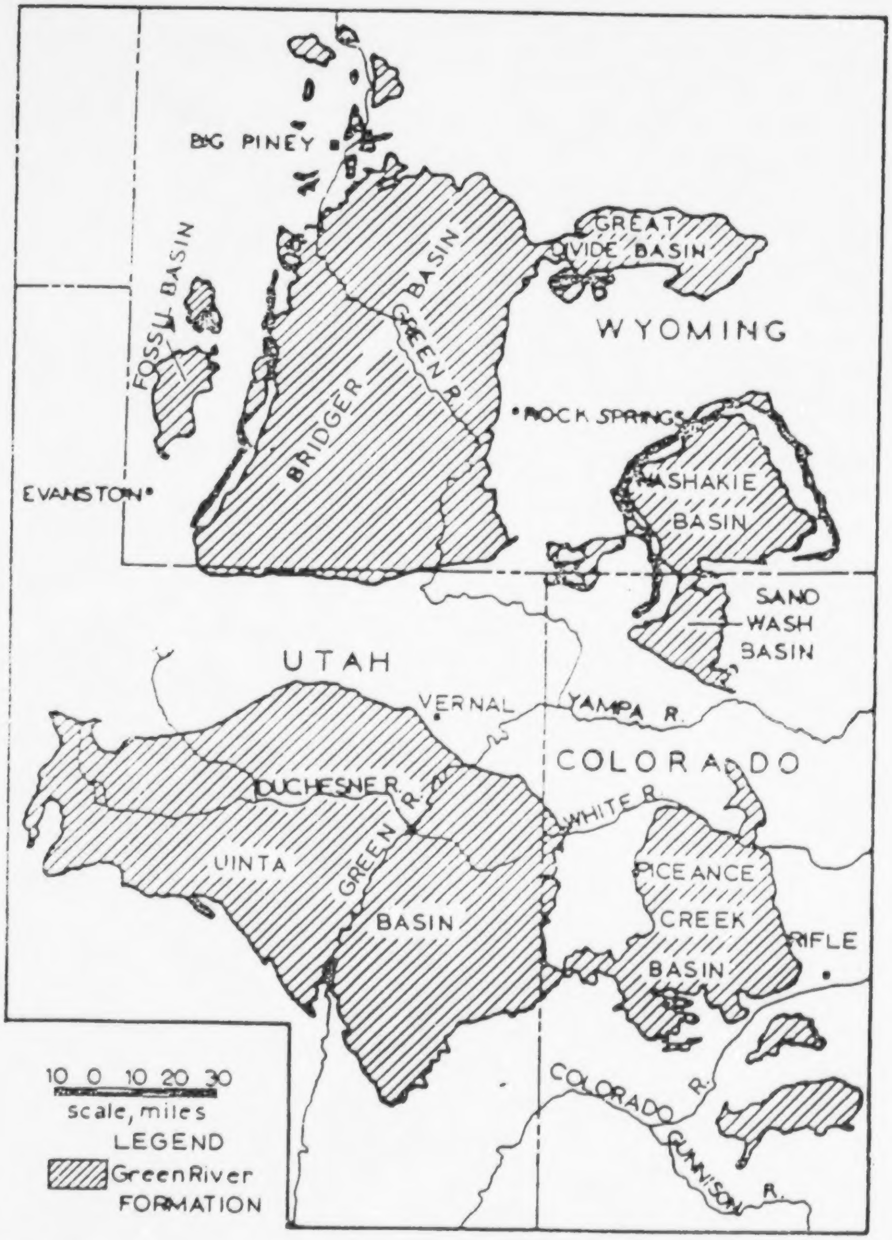


Fig. 136 Areas underlain by the Green River Formation

SYSTEM $NaHCO_3$ - Na_2CO_3 - $CaCO_3$ - H_2O

Figure 137

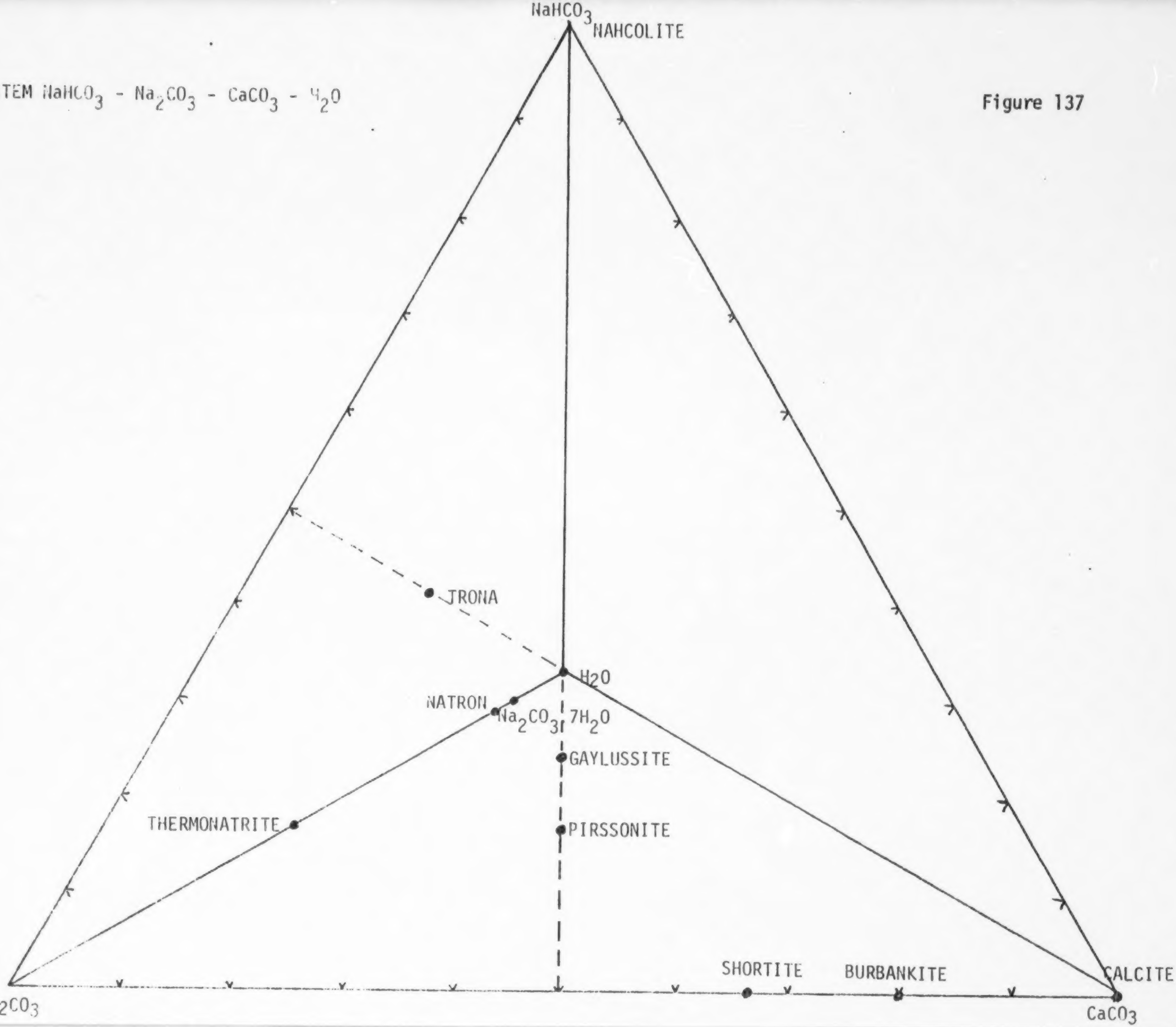


Figure 137

SYSTEM Na_2CO_3 - $CaCO_3$ - $MgCO_3$ - H_2O

Figure 138

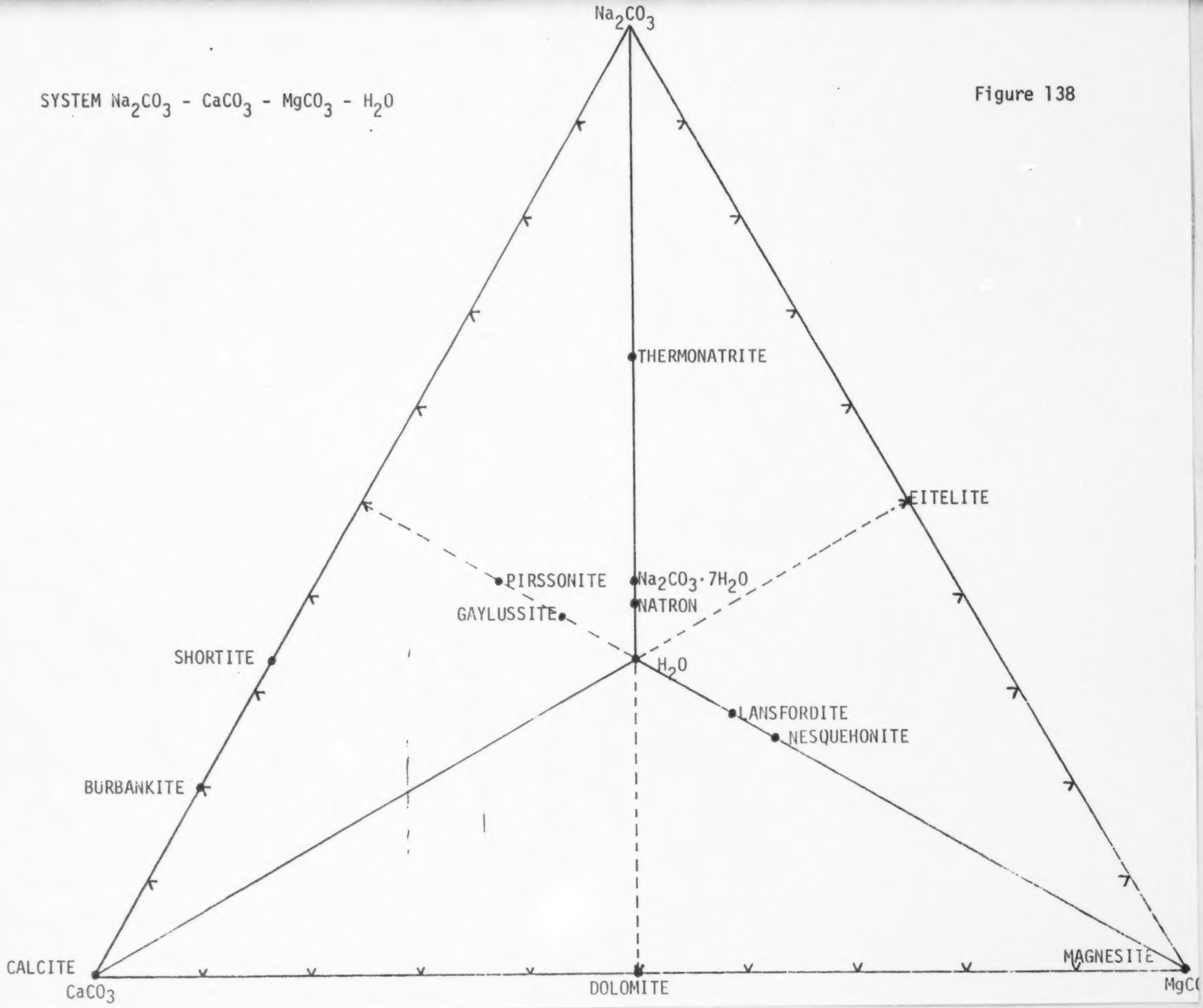


Figure 138

GENERALIZED STRATIGRAPHIC SECTION FOR THE SOUTHEASTERN GREEN RIVER BASIN

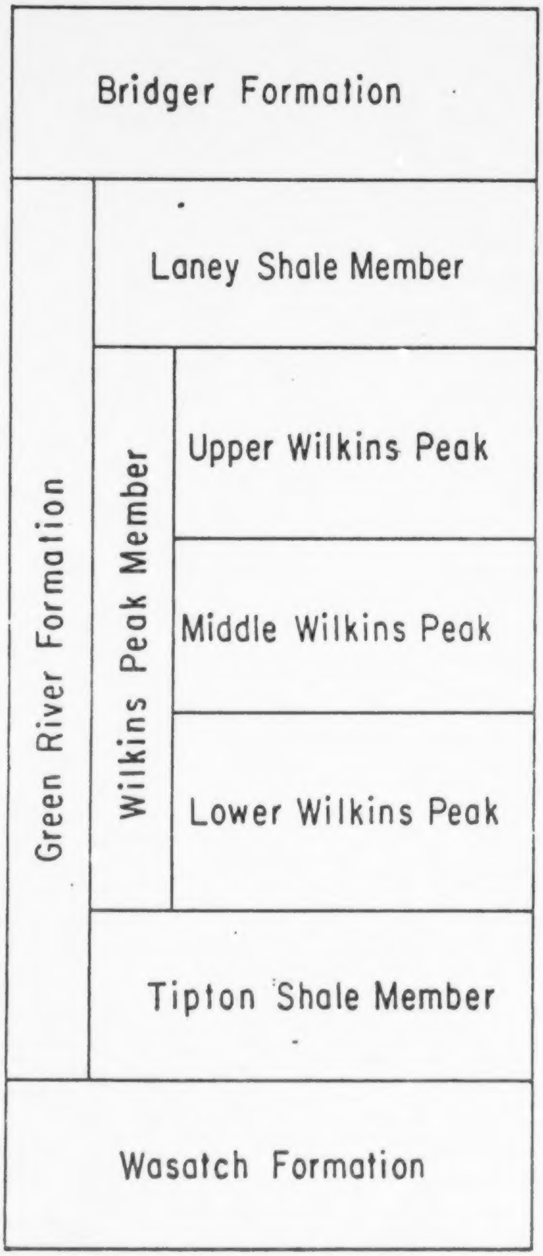
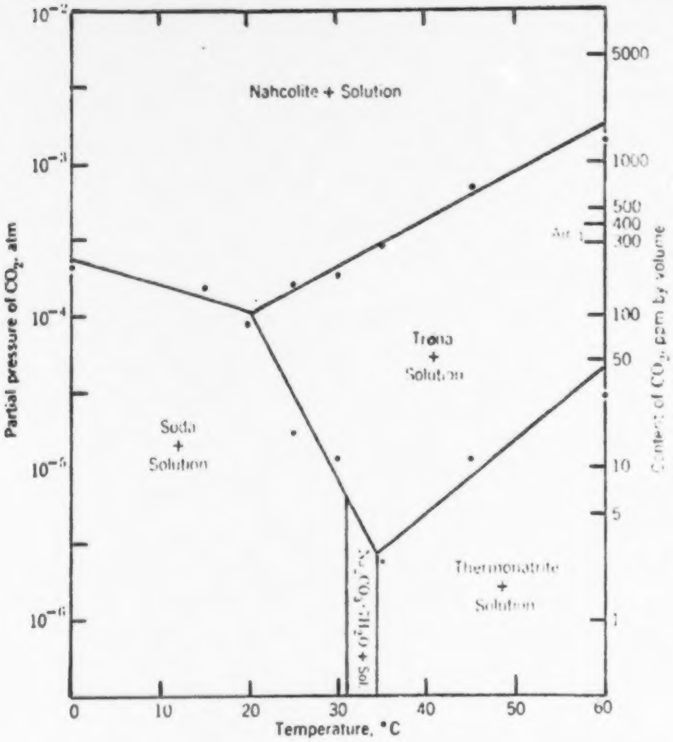
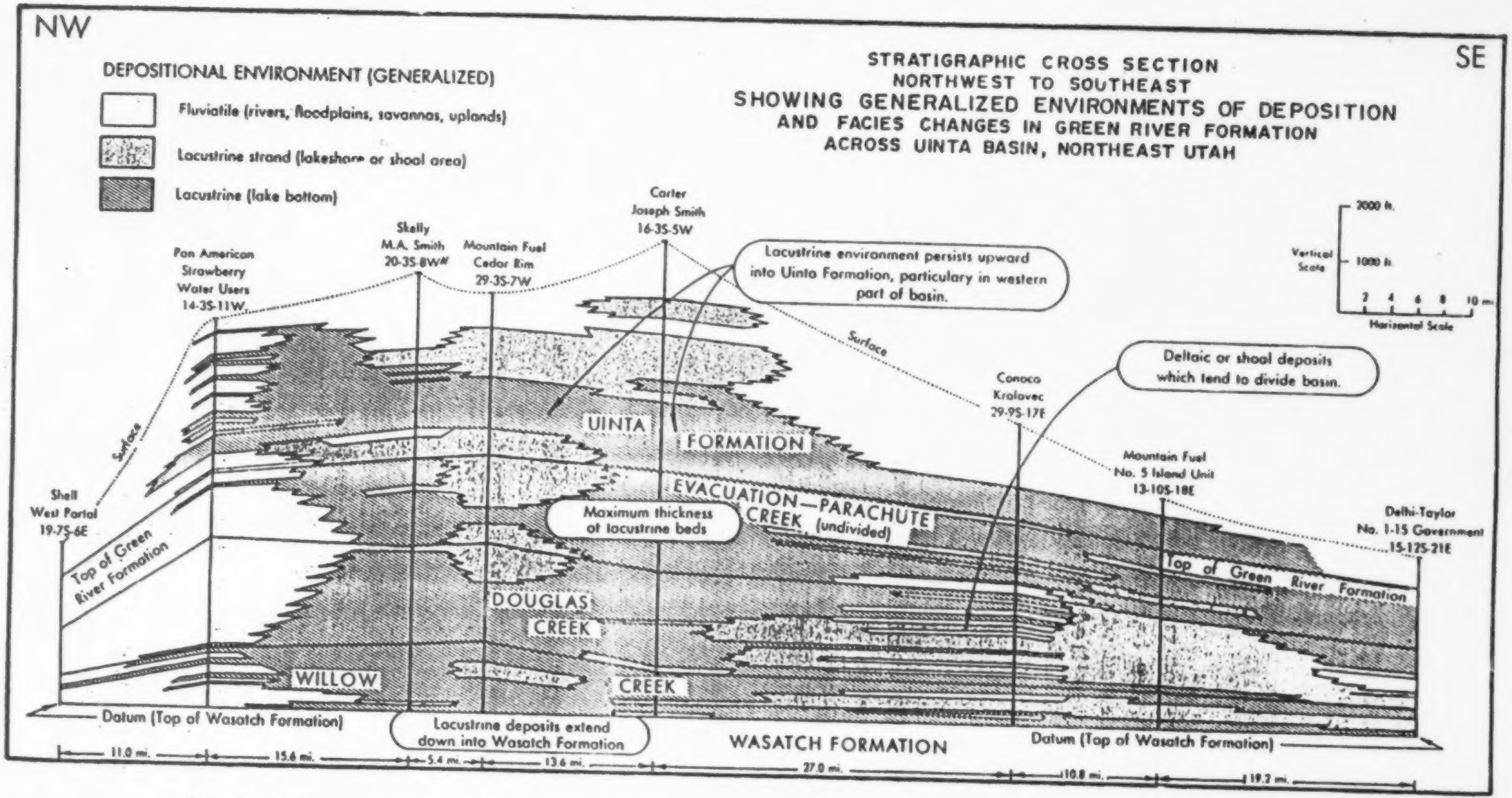


Figure 139



P_{CO_2}- T diagram of the system $NaHCO_3$ Na_2CO_3 H_2O. The CO_3 content of present-day air has been indicated on the right. Locations of phase boundaries were calculated from the data of Freeth (1923). (Milton and Eugster, 1959)

Figure 140


NW
SE
DEPOSITIONAL ENVIRONMENT (GENERALIZED)
Fluviatile (rivers, floodplains, savannas, uplands)
Lacustrine strand (lakeshore or shoal area)
Lacustrine (lake bottom)
STRATIGRAPHIC CROSS SECTION
NORTHWEST TO SOUTHEAST
SHOWING GENERALIZED ENVIRONMENTS OF DEPOSITION
AND FACIES CHANGES IN GREEN RIVER FORMATION
ACROSS UINTA BASIN, NORTHEAST UTAH
2000 ft.
1000 ft.
Vertical Scale
2 4 6 8 10 mi
Horizontal Scale
Shell West Portal 19-7S-6E
Pan American Strawberry Water Users 14-3S-11W
Skelly M.A. Smith 20-3S-8W
Mountain Fuel Cedar Rim 29-3S-7W
Carter Joseph Smith 16-3S-5W
Conoco Kralovec 29-9S-17E
Mountain Fuel No. 5 Island Unit 13-10S-18E
Delhi-Taylor No. 1-15 Government 15-12S-21E
Surface
Surface
Lacustrine environment persists upward into Uinta Formation, particulary in western part of basin.
Deltaic or shoal deposits which tend to divide basin.
Maximum thickness of lacustrine beds
Lacustrine deposits extend down into Wasatch Formation
Top of Green River Formation
Top of Green River Formation
UINTA
FORMATION
EVACUATION—PARACHUTE CREEK (undivided)
DOUGLAS CREEK
WILLOW
CREEK
WASATCH FORMATION
Datum (Top of Wasatch Formation)
Datum (Top of Wasatch Formation)
11.0 mi.
15.6 mi.
5.4 mi.
13.6 mi.
27.0 mi.
10.8 mi.
19.2 mi.

Stratigraphic cross section northwest to southeast showing generalized environments of deposition and facies changes in Green River Formation across Uinta Basin, northeast Utah.

262

Figure 141

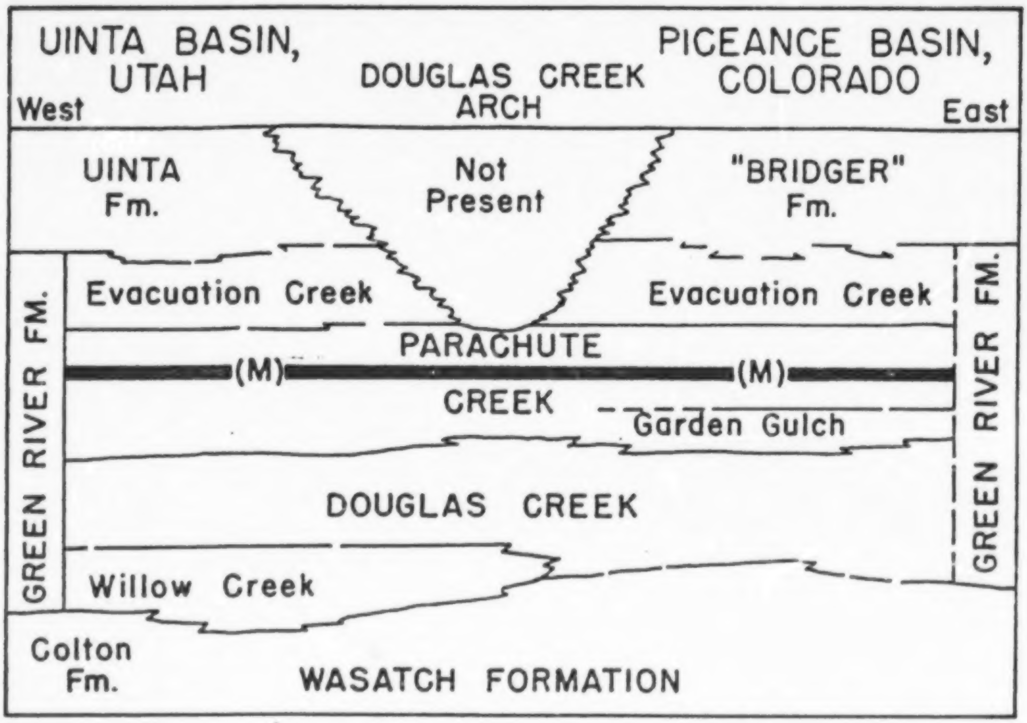
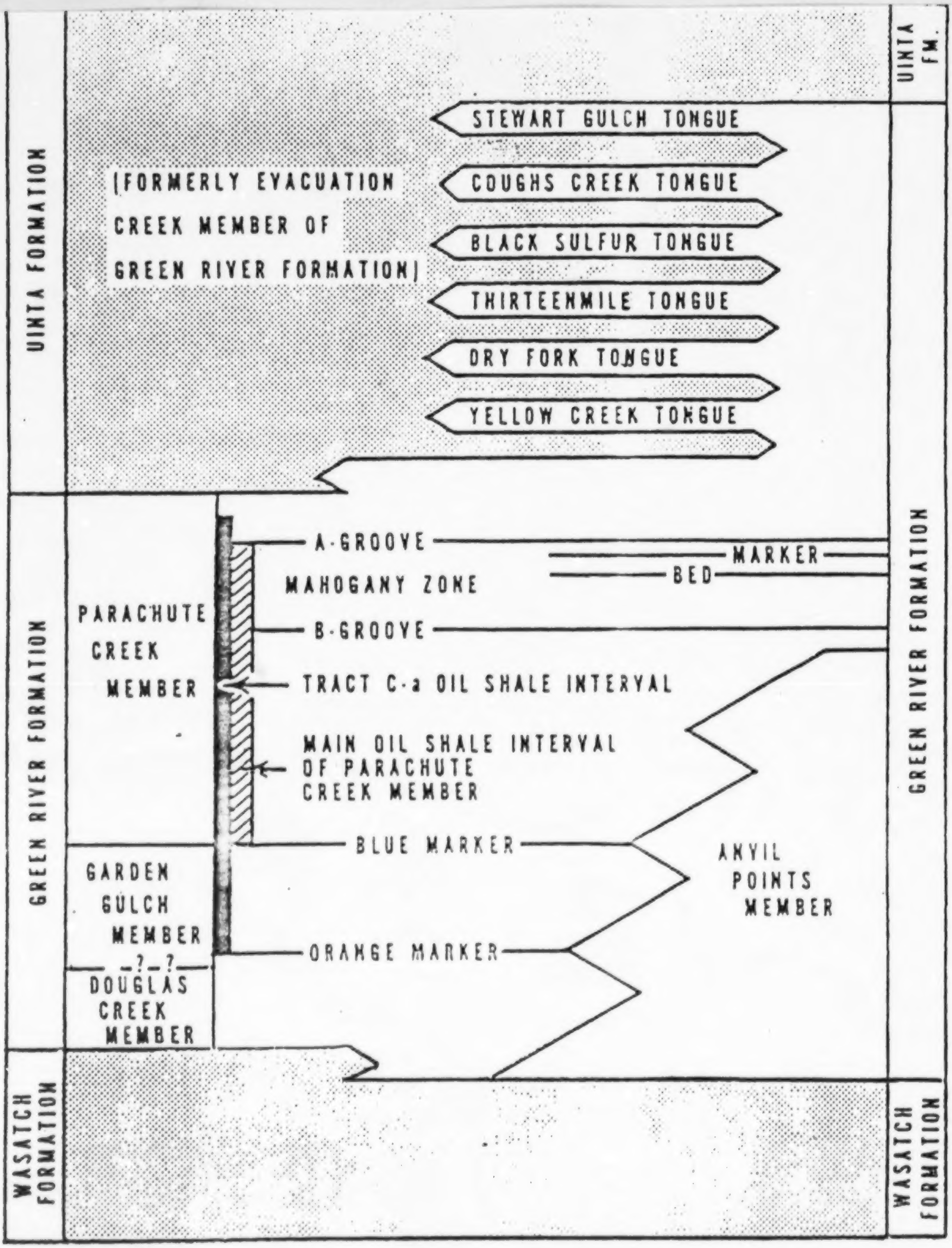


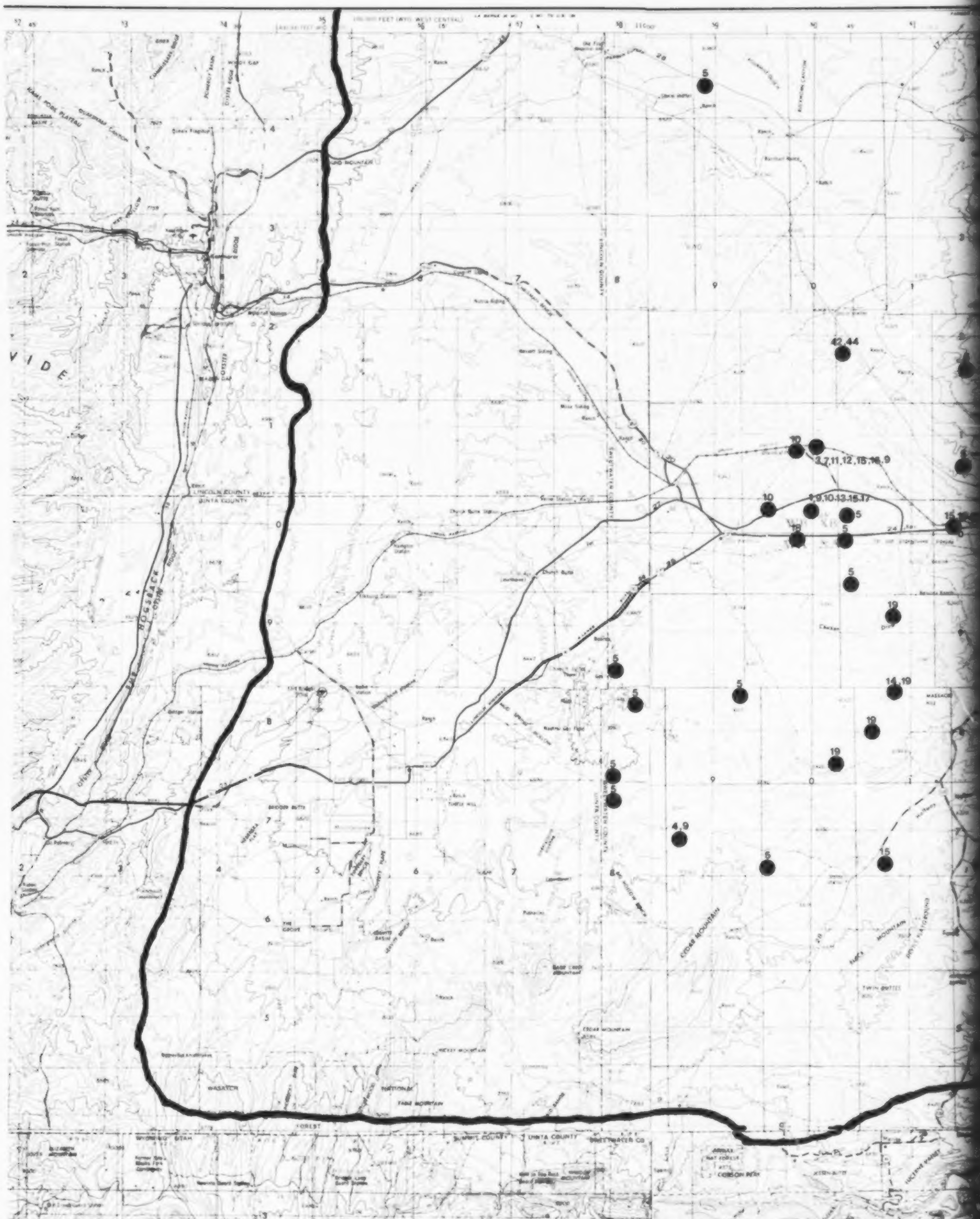
Fig. 142 Diagrammatic cross section west to east, Uinta to Piceance Basin. (M) indicates Mahogany Zone

Figure 142



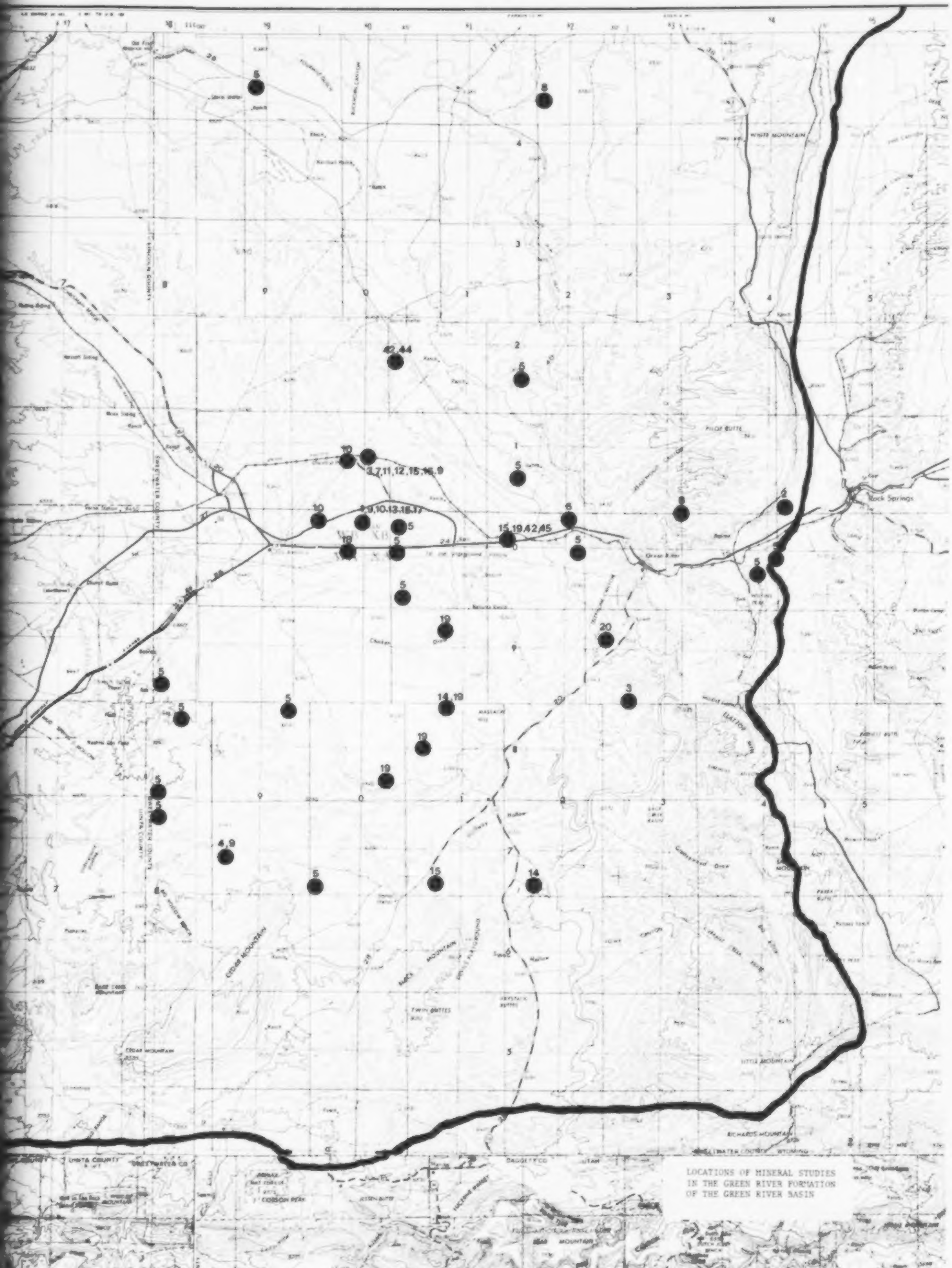
Diagrammatic stratigraphic section of Green River beds and adjacent formations in the Piceance Basin.

Figure 143

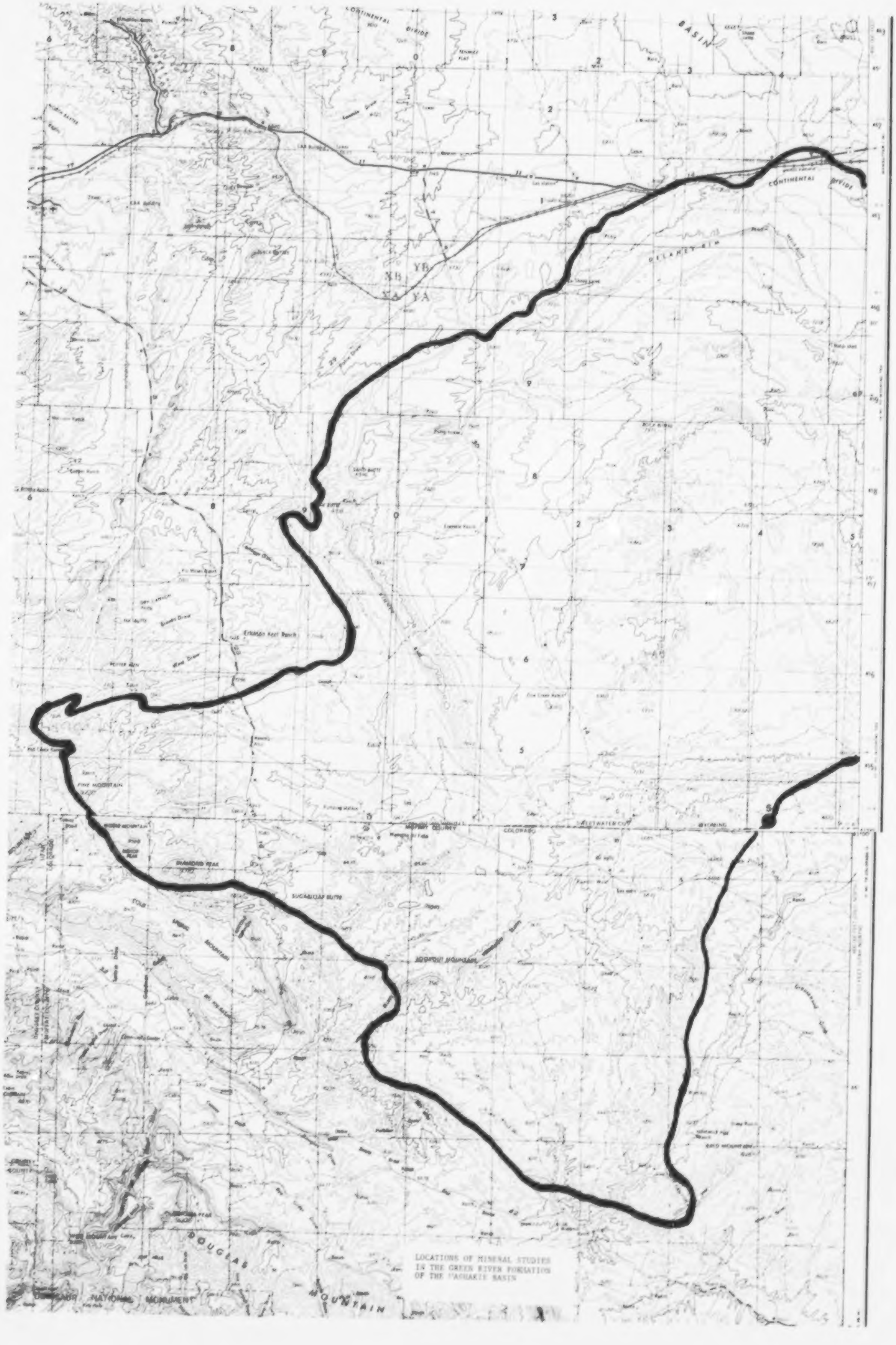


2(65

Figure 144



LOCATIONS OF MINERAL STUDIES
IN THE GREEN RIVER FORMATION
OF THE GREEN RIVER BASIN



LOCATIONS OF MINERAL STUDIES
IN THE GREEN RIVER FORMATION
OF THE WASHAKIE BASIN

FIGURE 145

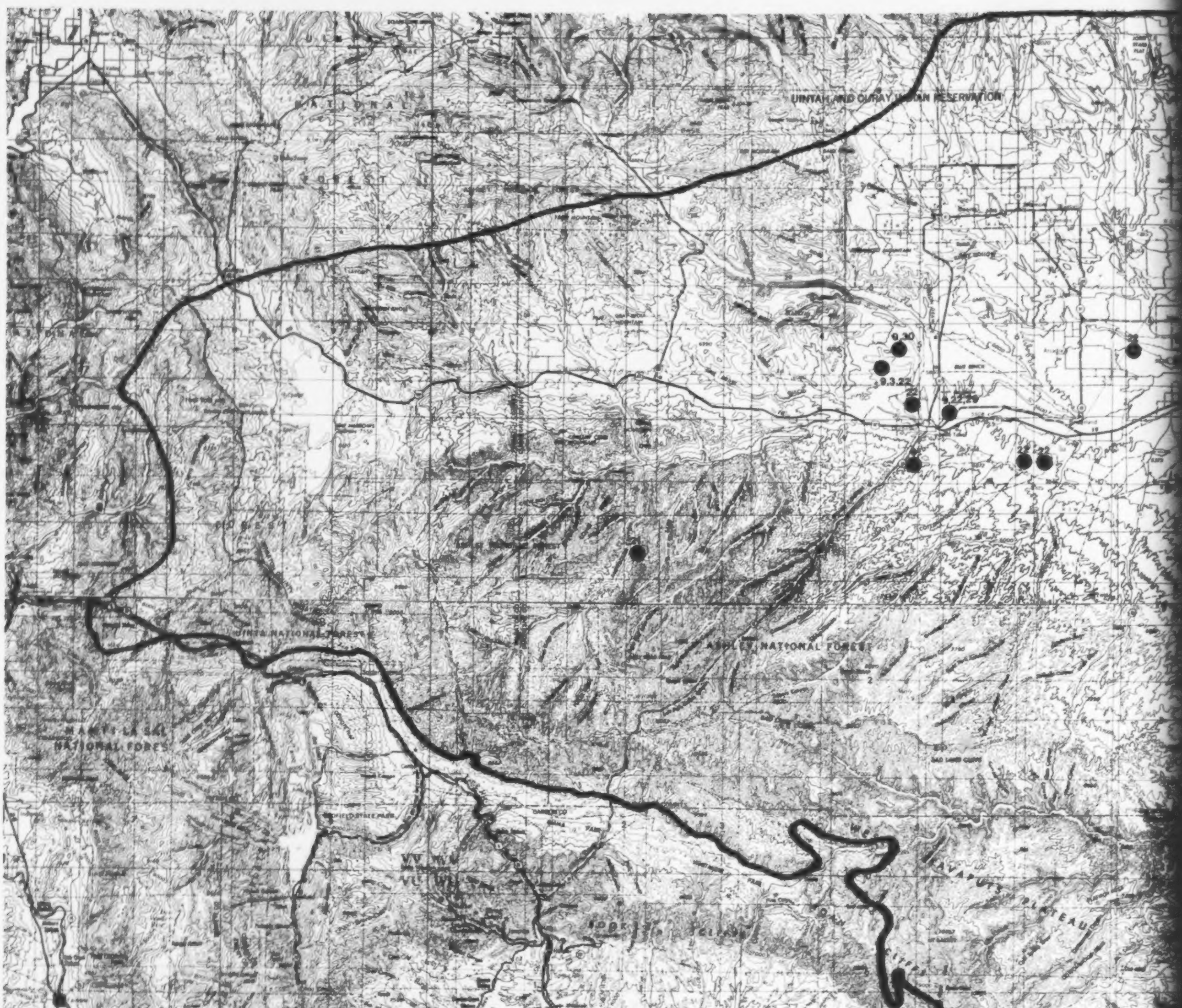
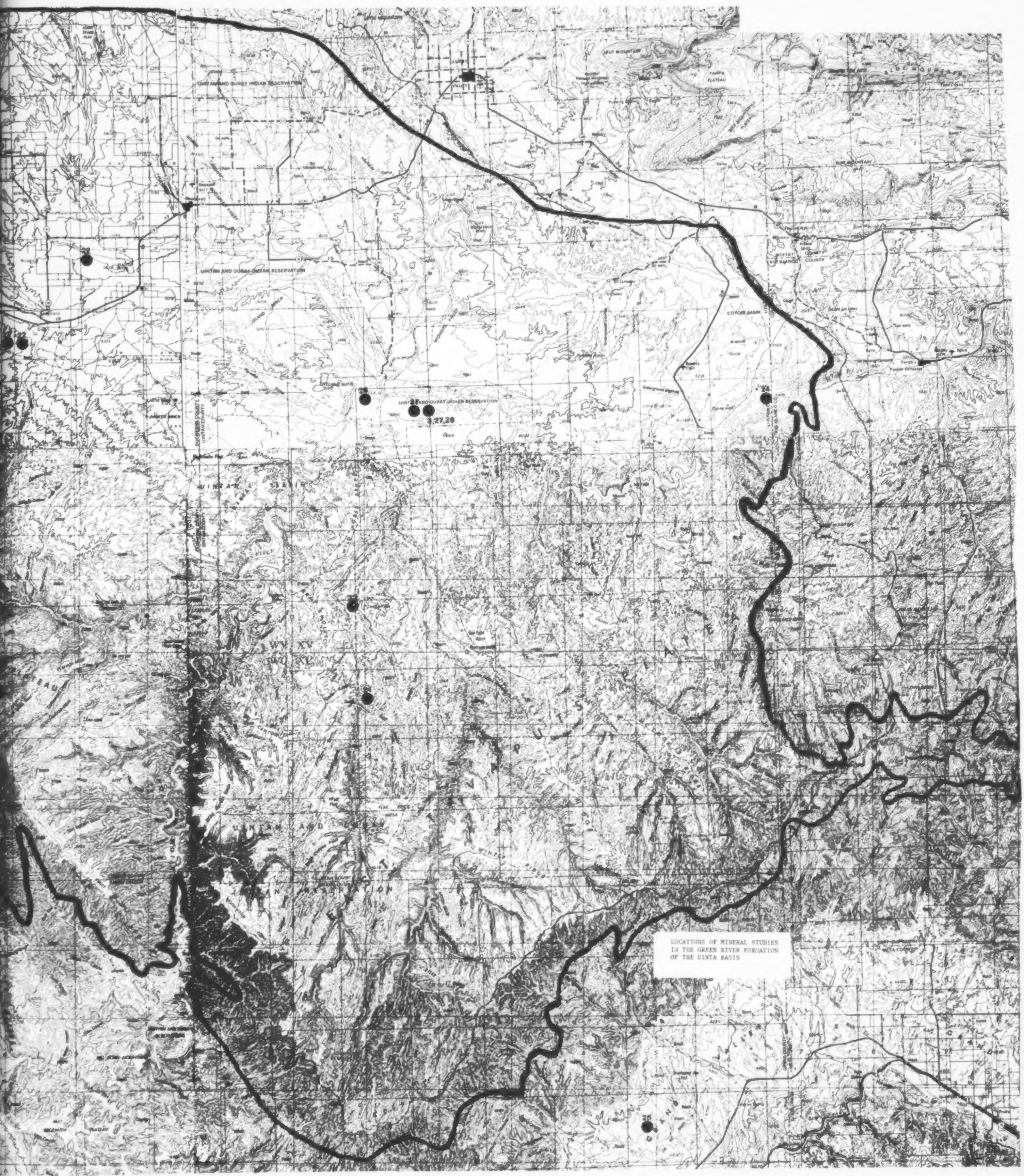

UINTAH AND OURAY INDIAN RESERVATION
UINTA NATIONAL FOREST
ASHLEY NATIONAL FOREST
MANTI-LA SAL NATIONAL FOREST
TAVAPUTS PLATEAU
MANTI-LA SAL NATIONAL FOREST

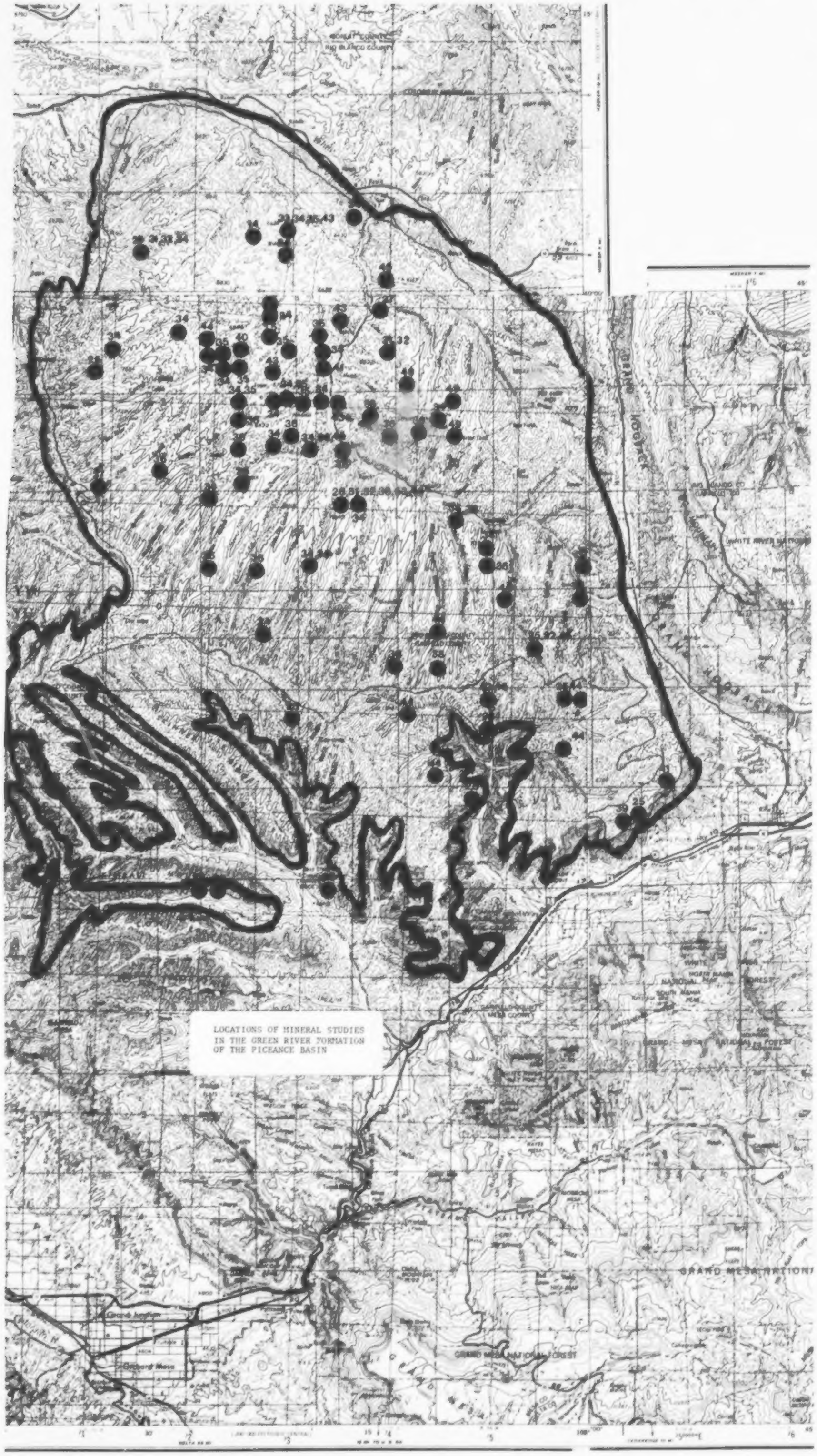
Figure 146


UINTAH AND OURAY INDIAN RESERVATION
UINTAH AND OURAY INDIAN RESERVATION
UINTAH AND OURAY INDIAN RESERVATION
COYOTE BASIN
MOFFAT COUNTY
RIO BLANCO COUNTY
26
22
23
27
3,27,28
24
25

LOCATIONS OF MINERAL STUDIES
IN THE GREEN RIVER FORMATION
OF THE UINTA BASIN

267-a

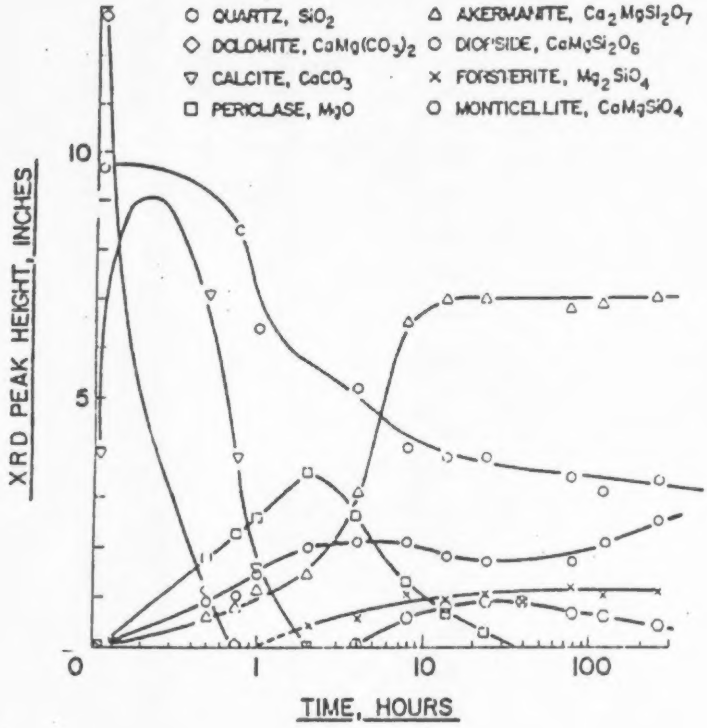
FIGURE 146



LOCATIONS OF MINERAL STUDIES IN THE GREEN RIVER FORMATION OF THE PICEANCE BASIN

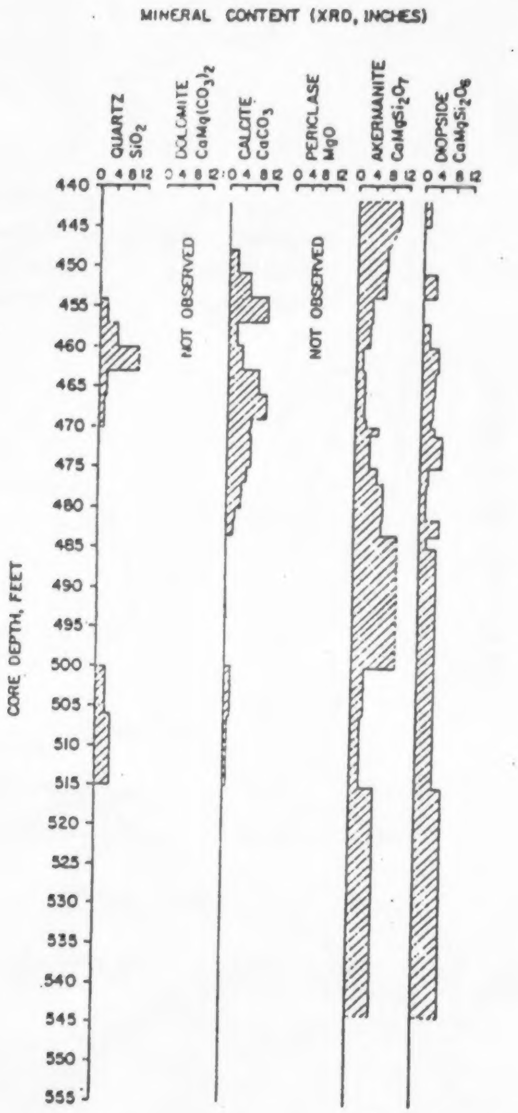
FIGURE 147

SECTION 3
WATER CHEMISTRY FIGURES



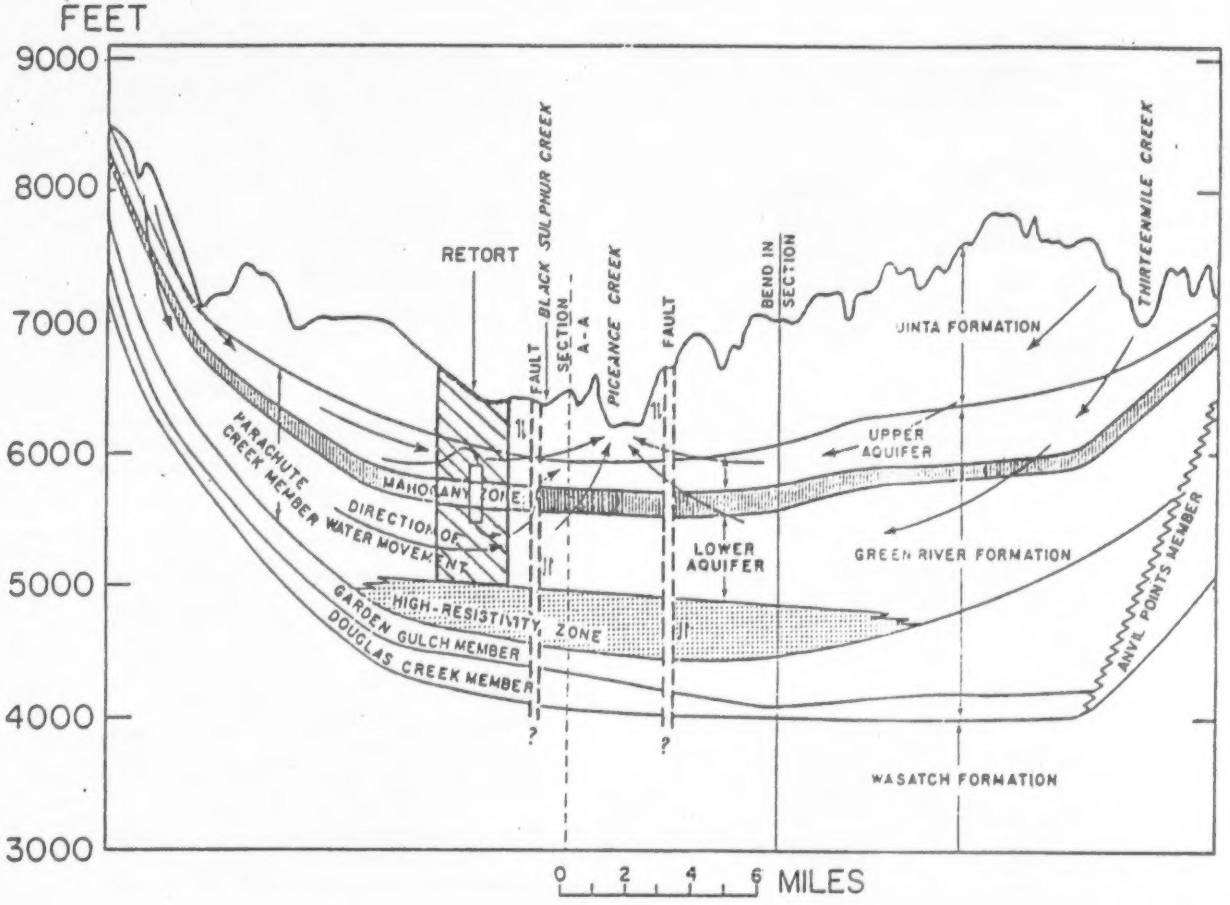
Mineral content changes in artificial shale pellets during heating. Relative x-ray diffraction peak heights vs. time at 760°C under 1% O_2/N_2 atmosphere.

Figure 148



Retort 3E spent shale core mineral histogram. Relative x-ray diffraction peak heights vs. depth.

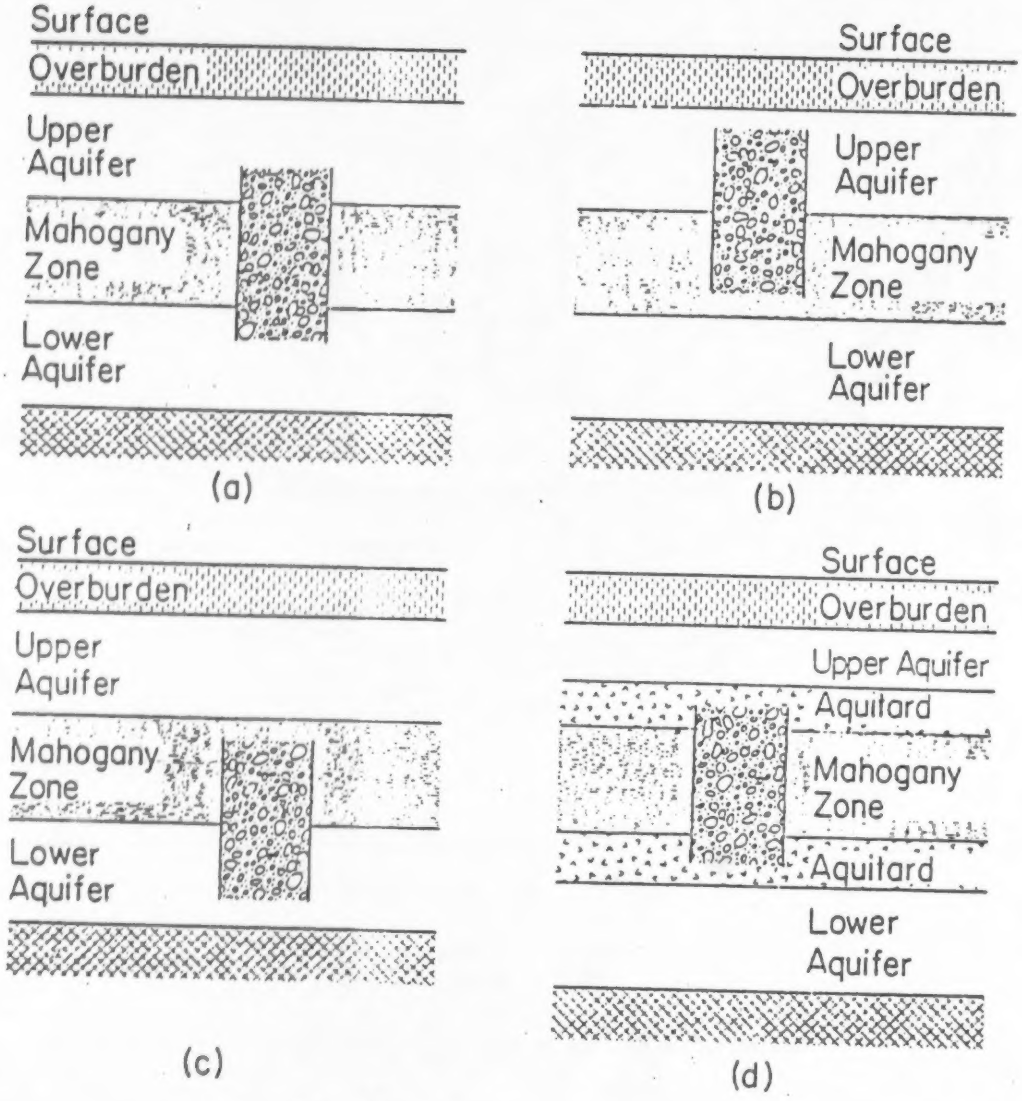
Figure 149



VERTICAL EXAGGERATION X 21
DATUM IS MEAN SEA LEVEL

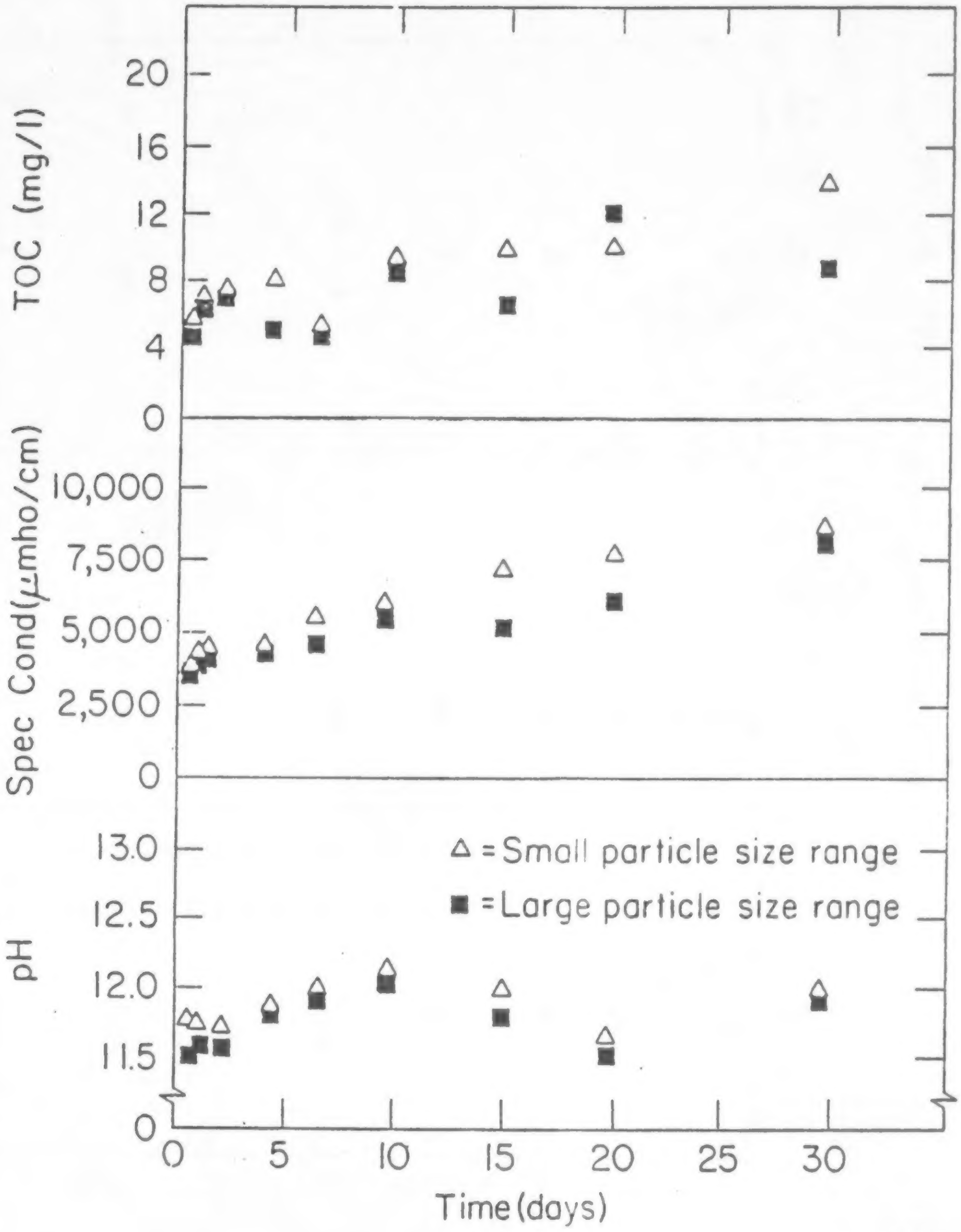
Geohydrologic section through the Piceance Basin. XBL 7811-12780

Figure 150



Retort/aquifer configurations.

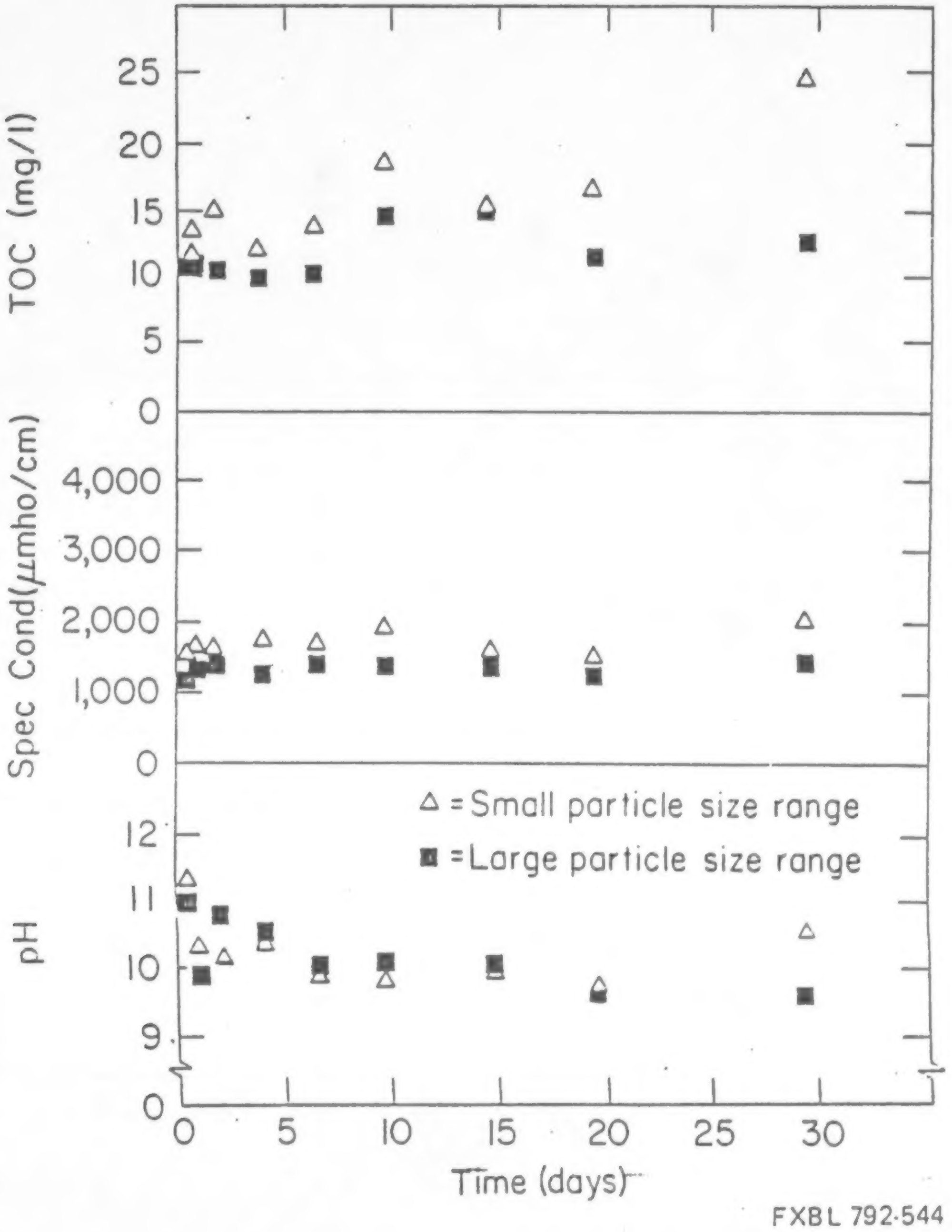
Figure 151



XBL 792-535

Distilled water batch experiments examining Type 1 spent shale at 20°C.

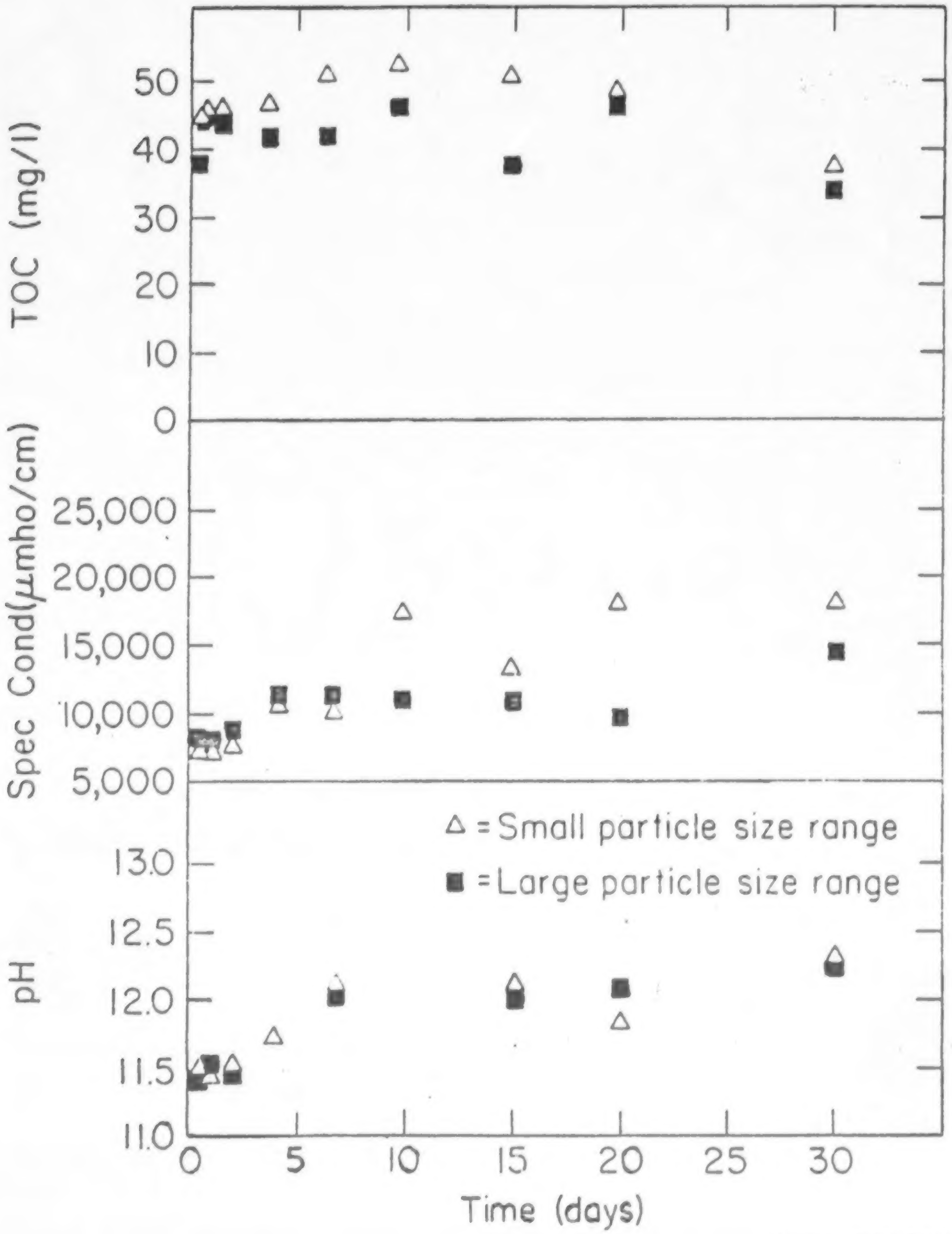
Figure 152



Distilled water batch experiments examining Type 2 spent shale at 20°C.

275

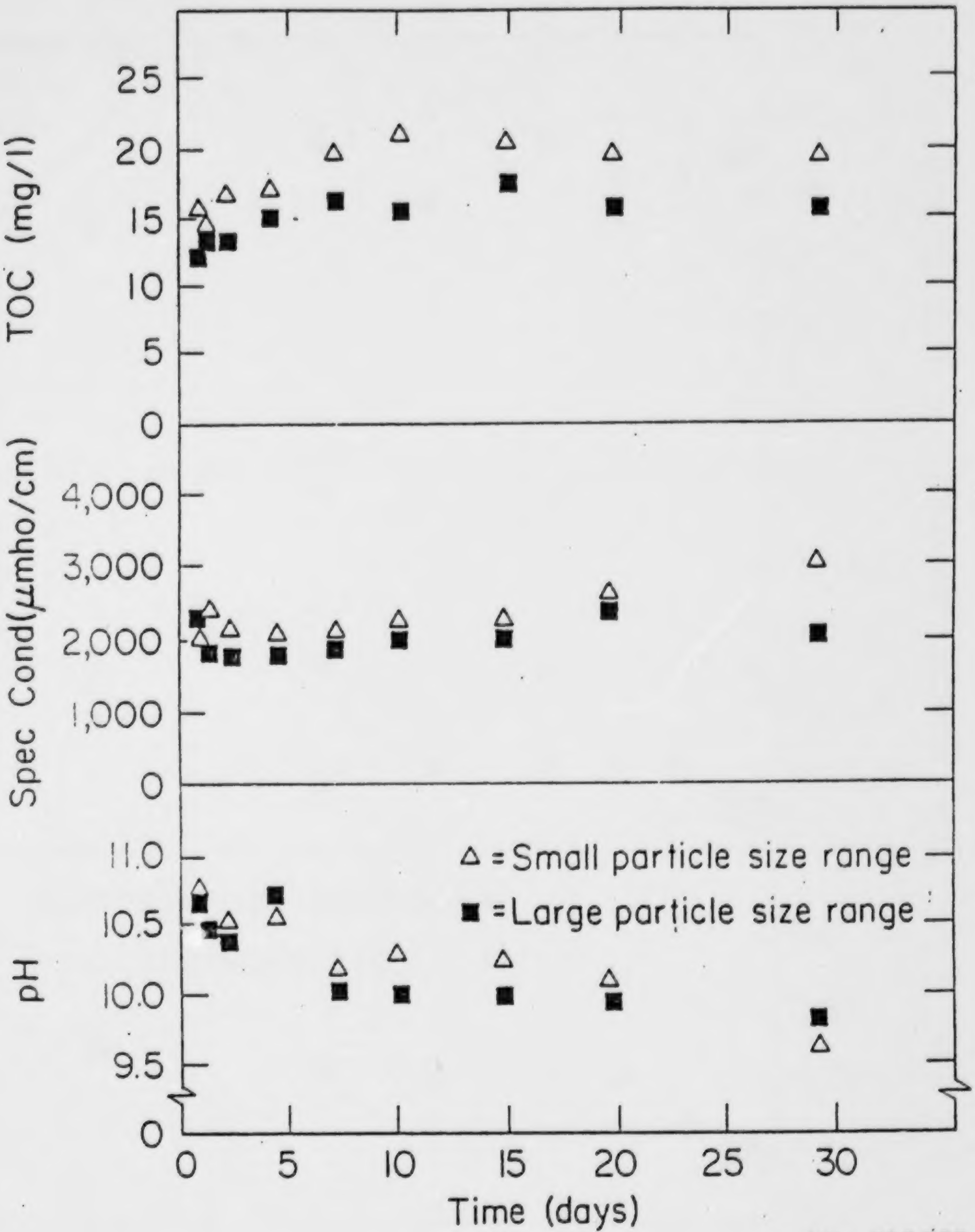
Figure 153



FXBL 792-564

[1]Distilled water batch experiments examining Type 3 spent shale at 20°C.

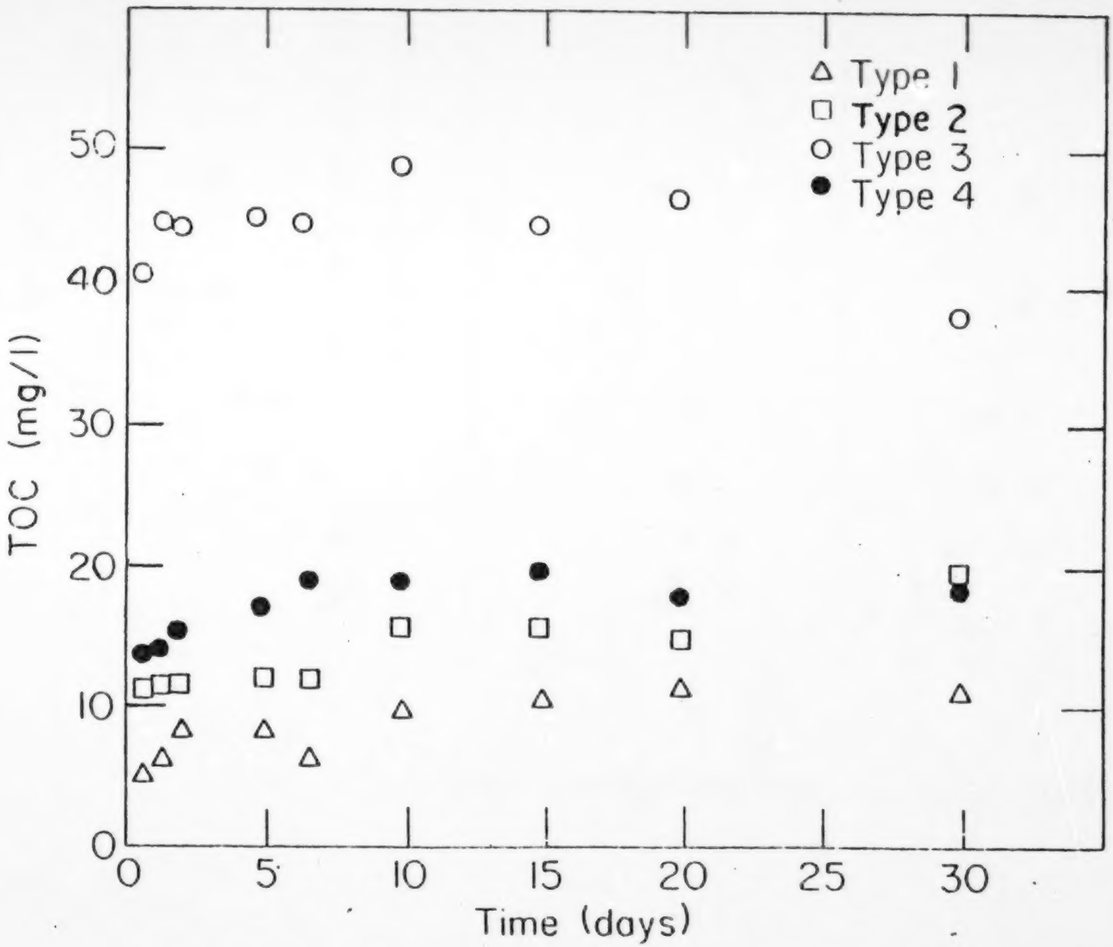
Figure 154



XBL 792-527

Distilled water batch experiments examining Type 4 spent shale at 20°C.

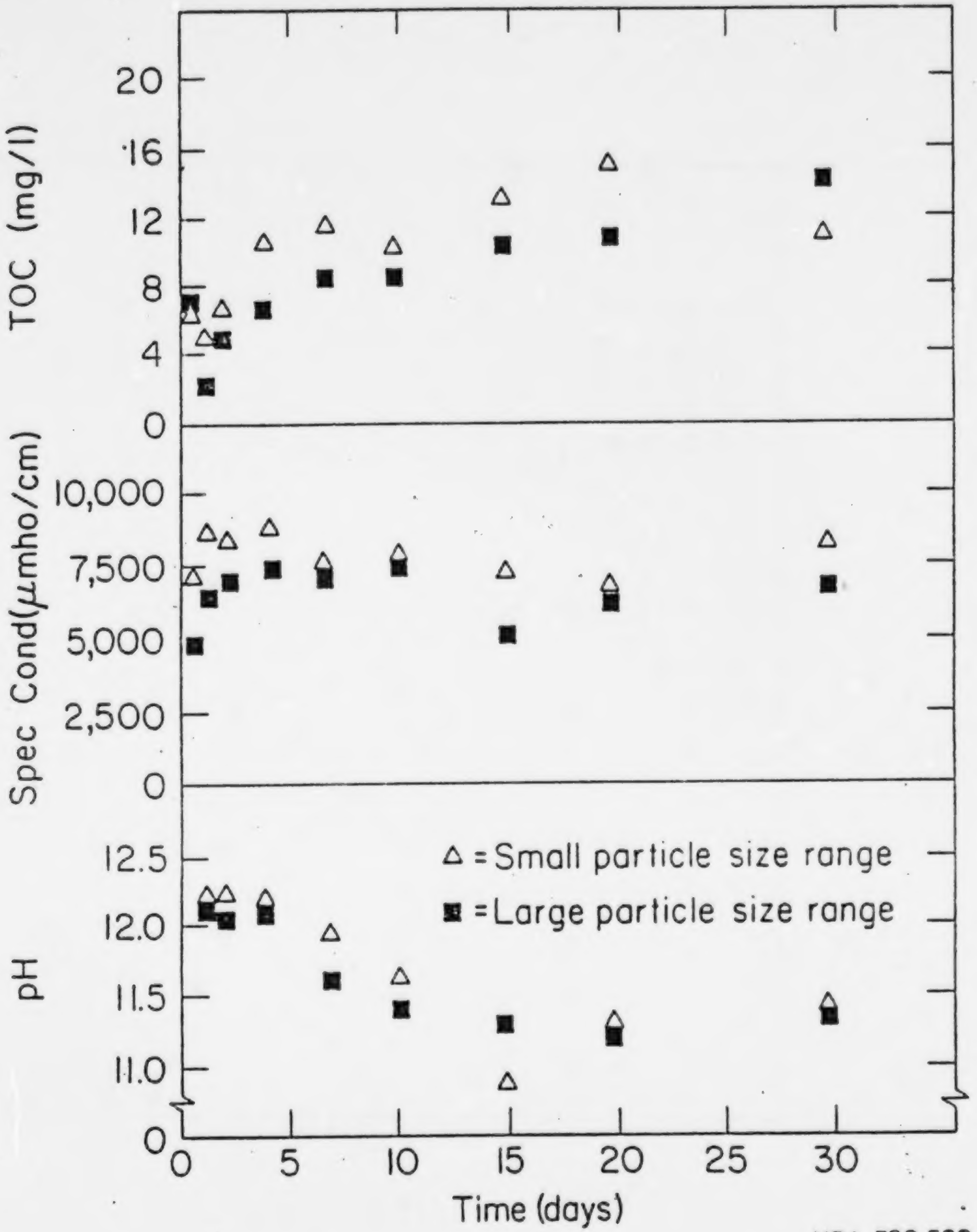
Figure 155



XBL 792 528

Summary of distilled water batch experiments conducted at a water temperature of 20° C.

Figure 156

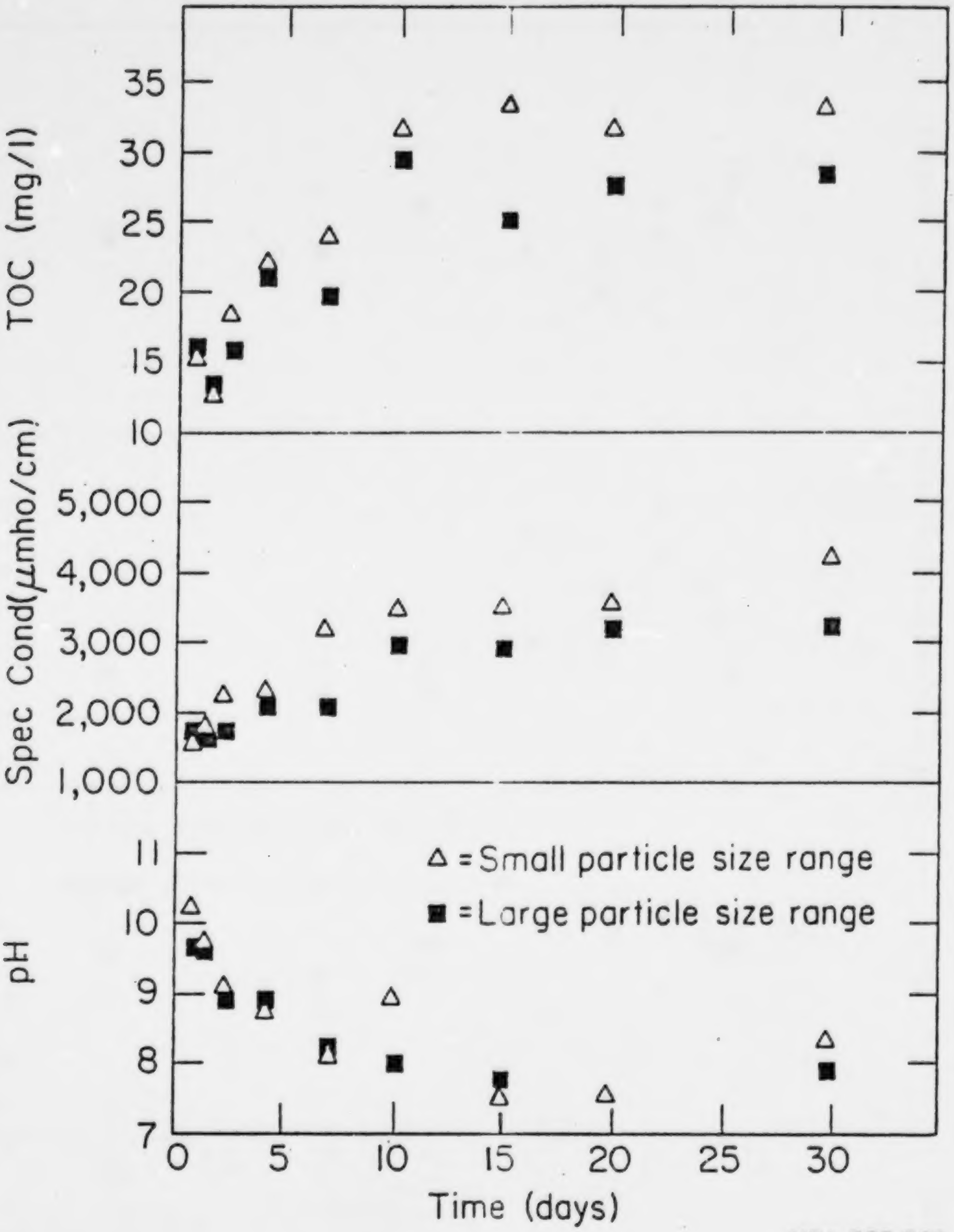


XBL 792-529

Distilled water batch experiments examining Type 1 spent shale at 80°C.

279

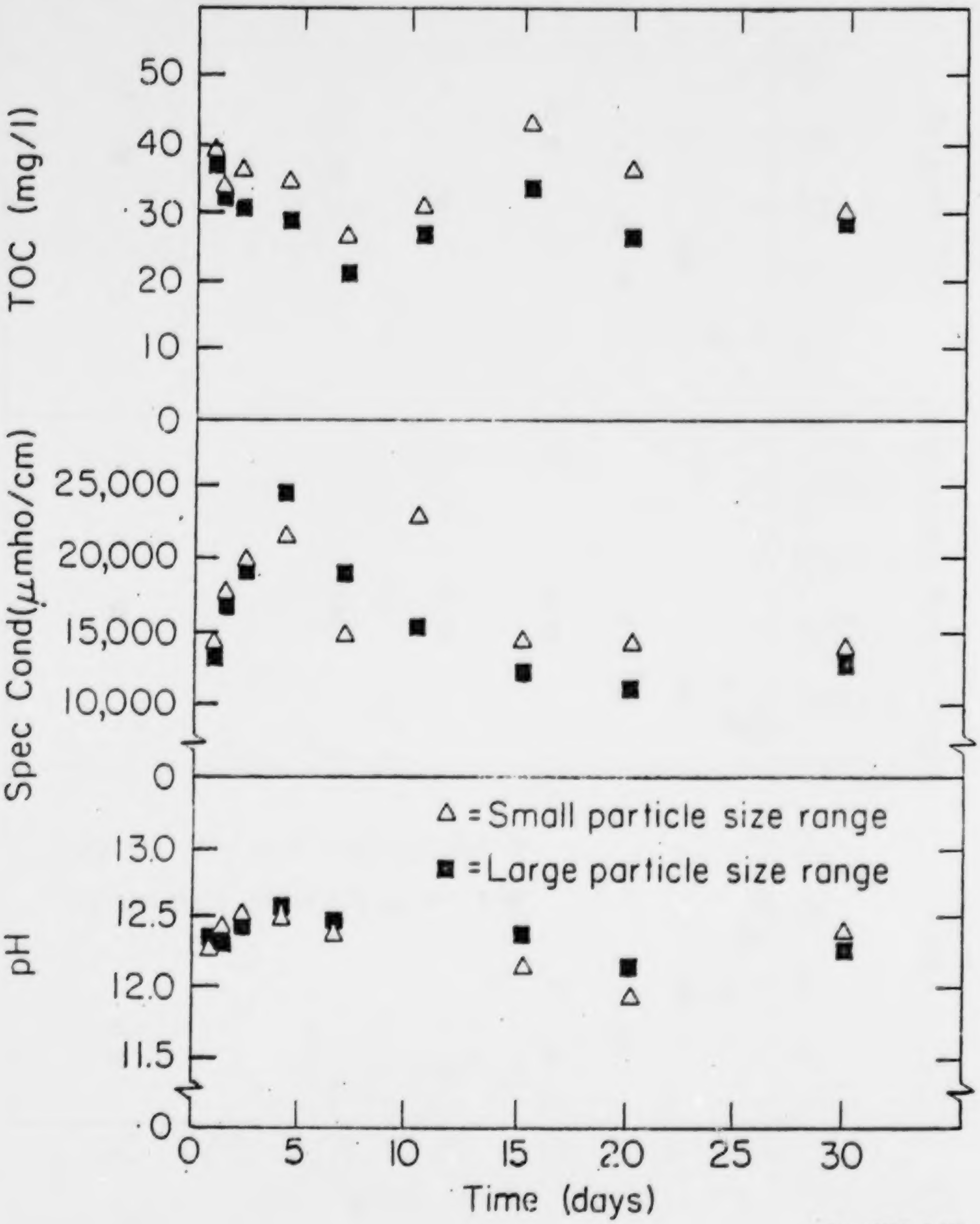
Figure 157



XBL 792-530

Distilled water batch experiments examining Type 2 spent shale at 80°C.

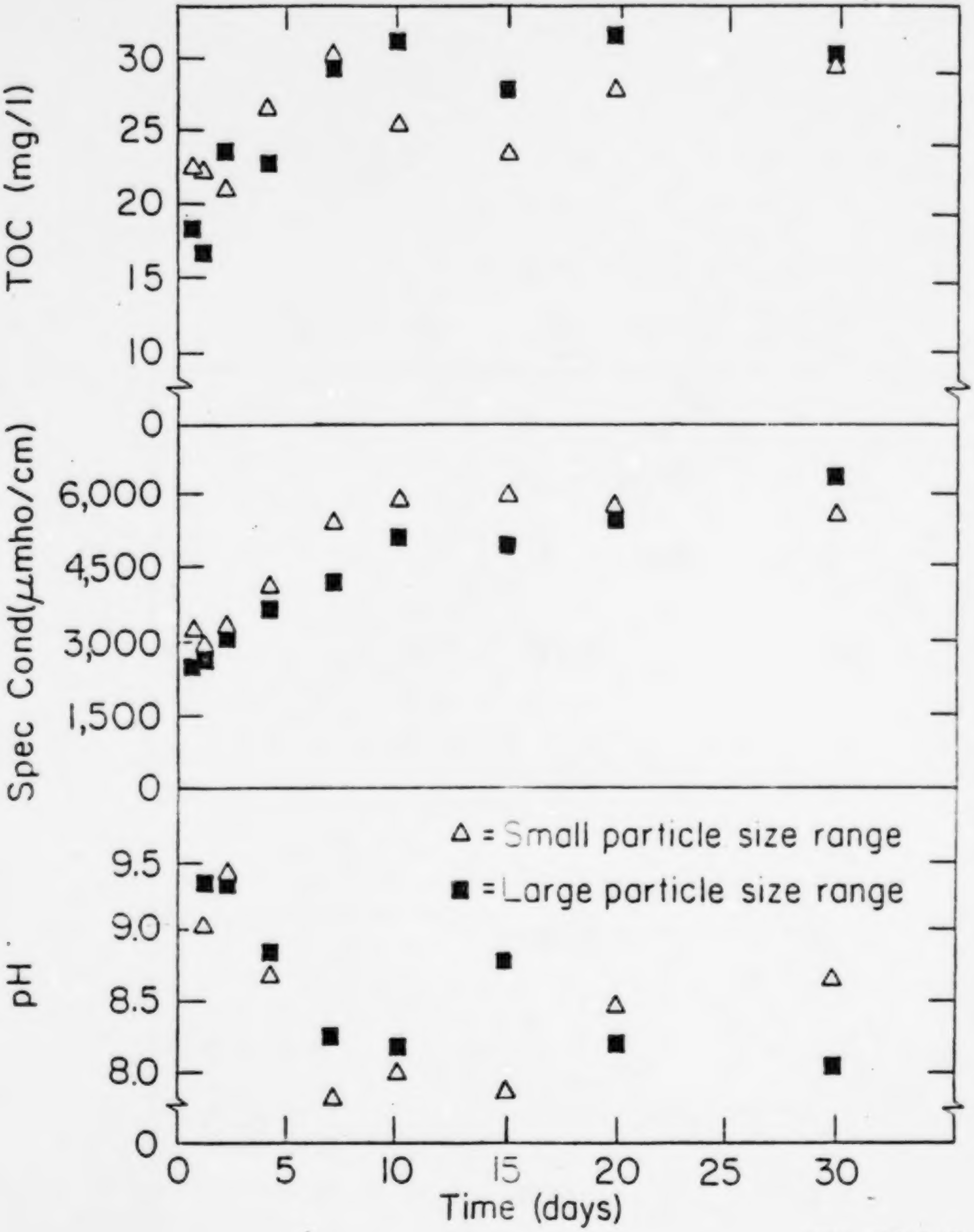
Figure 158



XBL 792-542

Distilled water batch experiments examining Type 3 spent shale at 80°C.

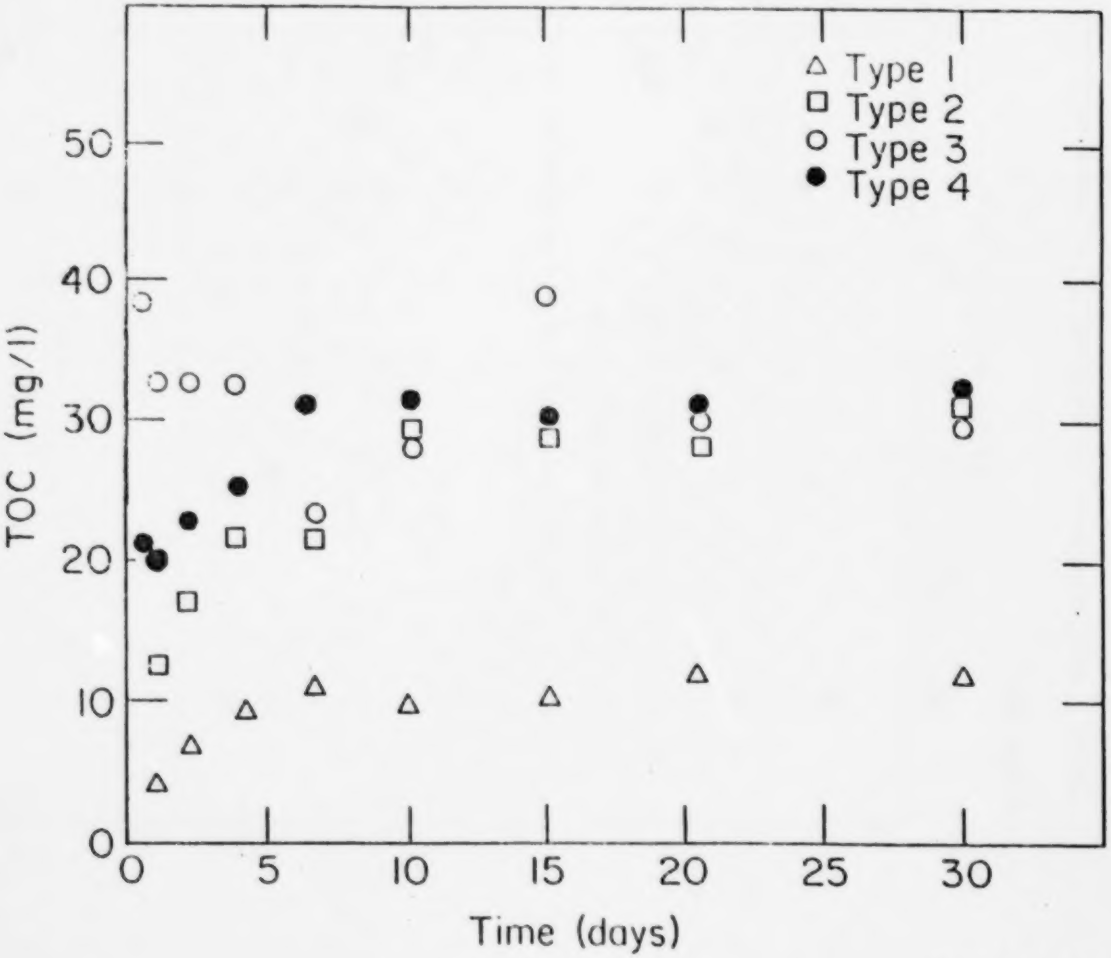
Figure 159



XBL 792-543

Distilled water batch experiments examining Type 4 spent shale at 80°C.

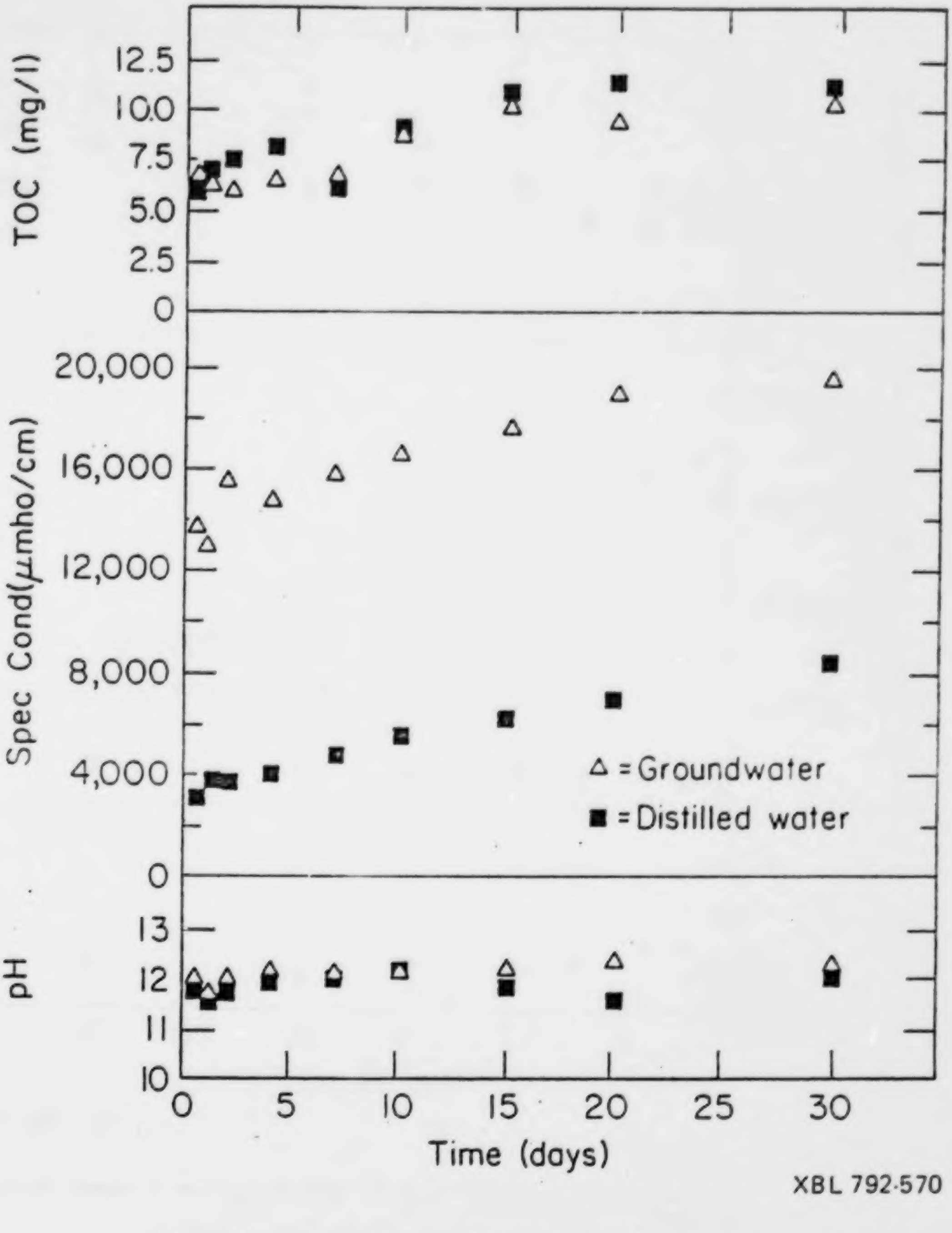
Figure 160



XBL 792-569

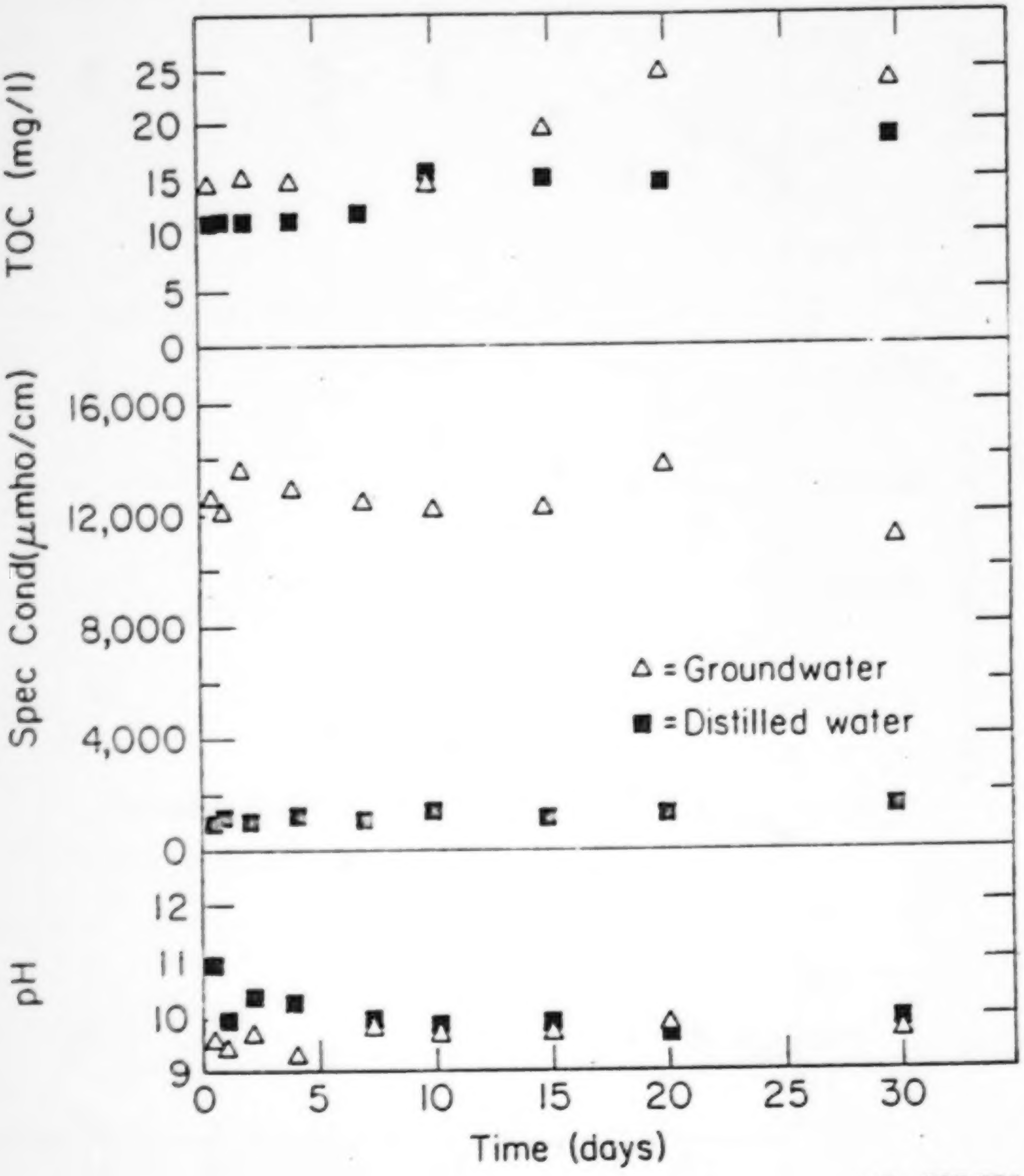
Summary of distilled water batch experiments conducted at a water temperature of 80°C.

Figure 161



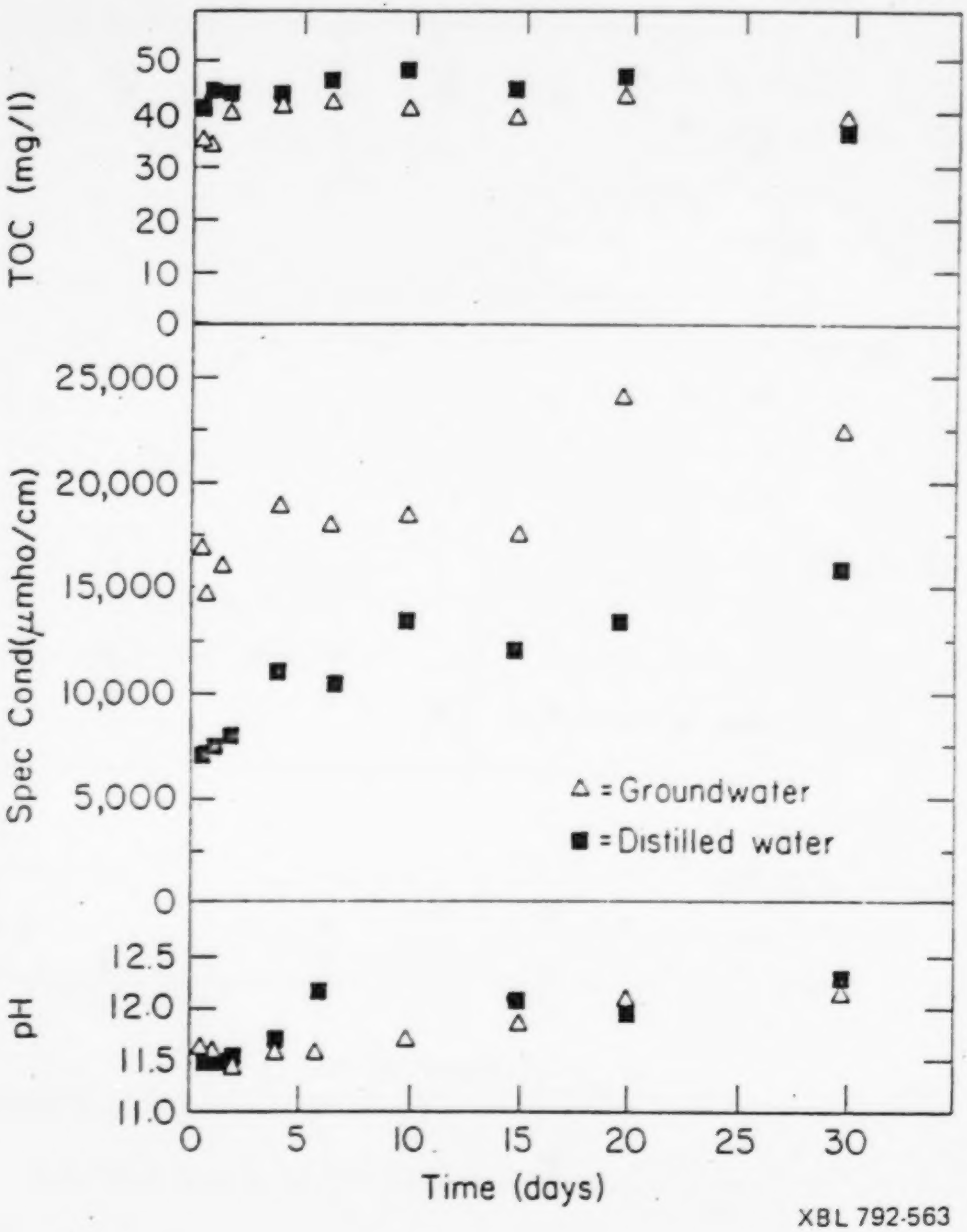
Groundwater batch experiments examining Type 1 spent shale at 20°C.

Figure 162



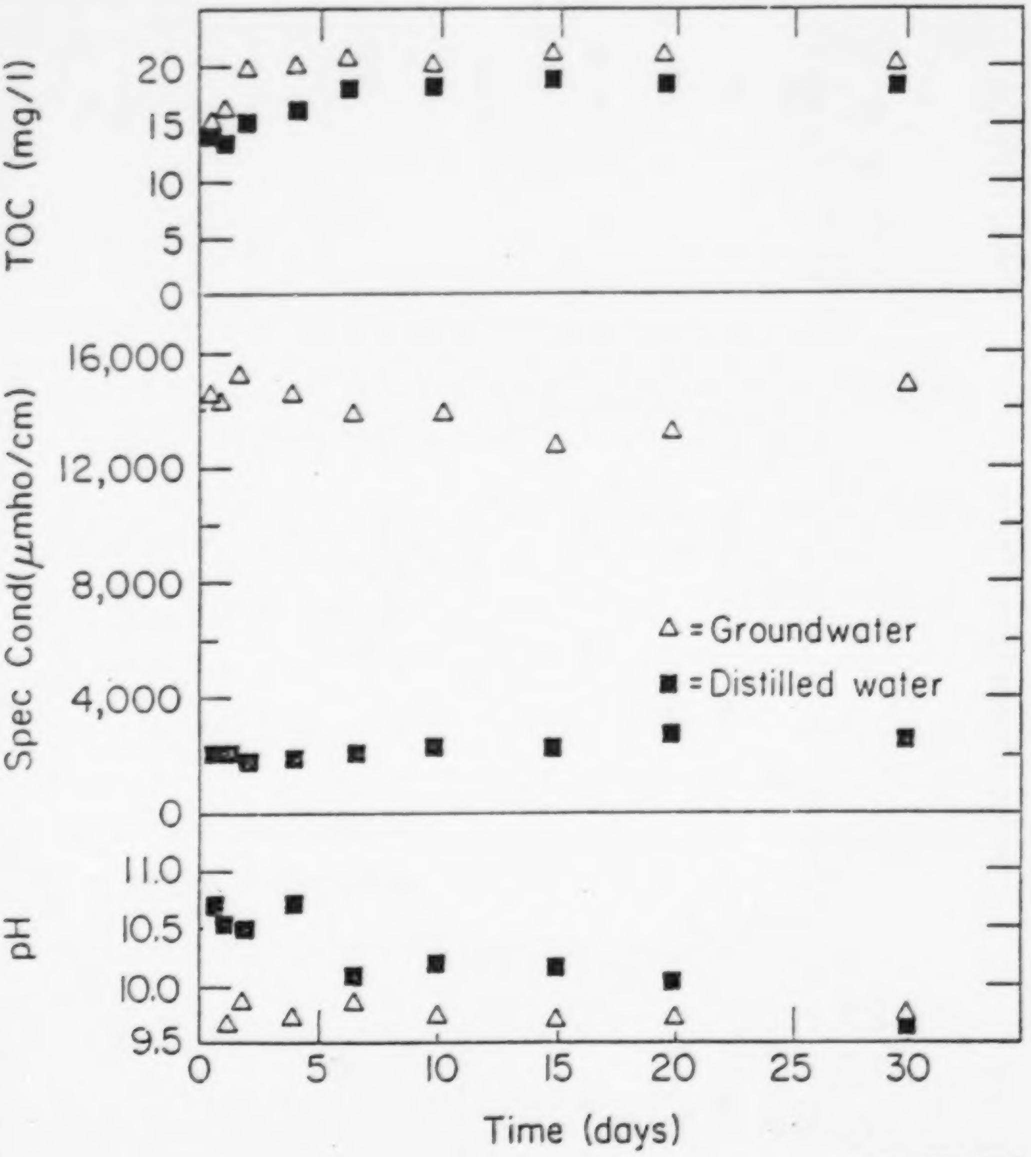
Groundwater batch experiments examining Type 2 spent shale at 20°C.

Figure 163



Groundwater batch experiments examining Type 3 spent shale at 20°C.

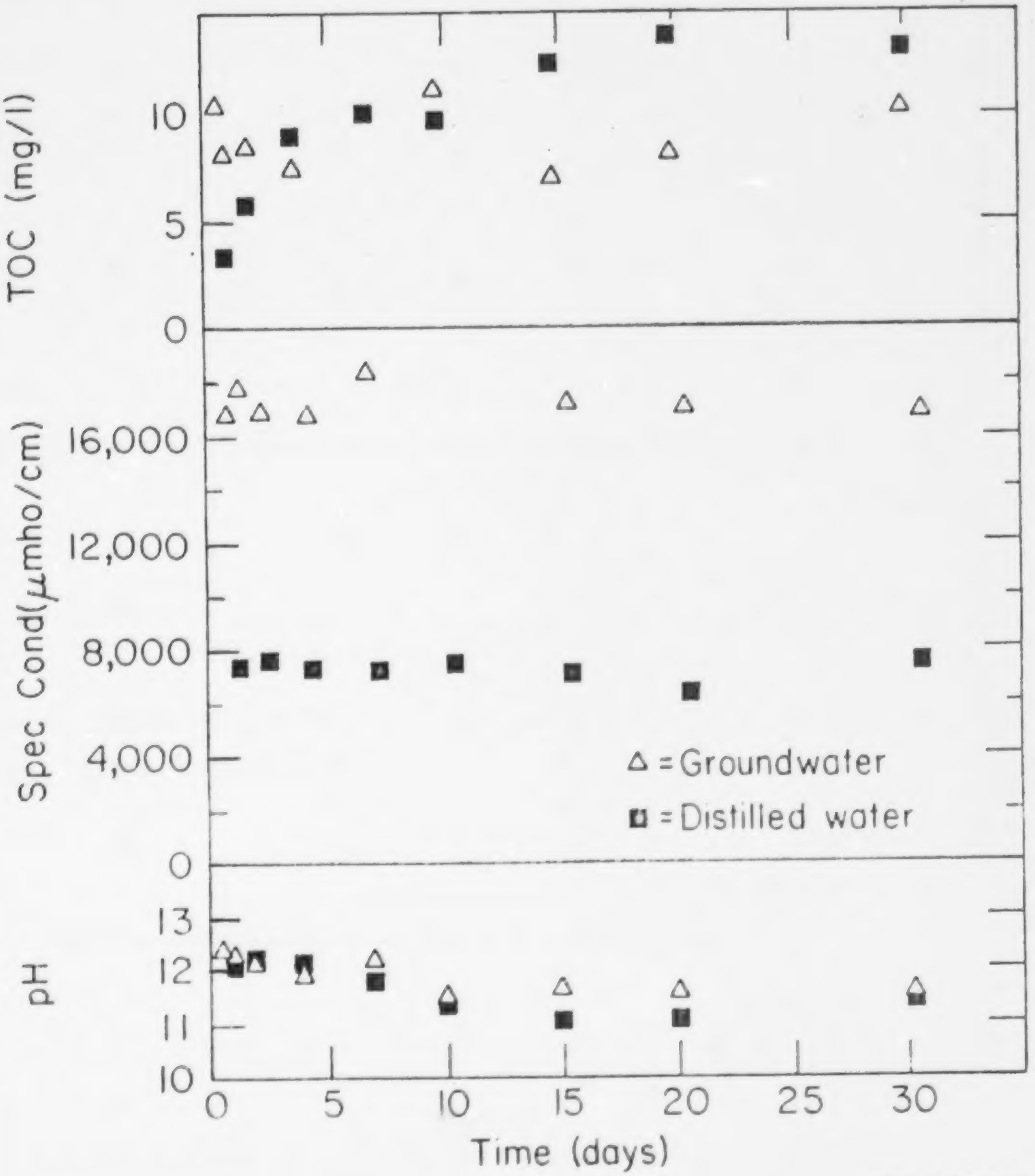
Figure 164



XBL 792-572

Groundwater batch experiments examining Type 4 spent shale at 20°C.

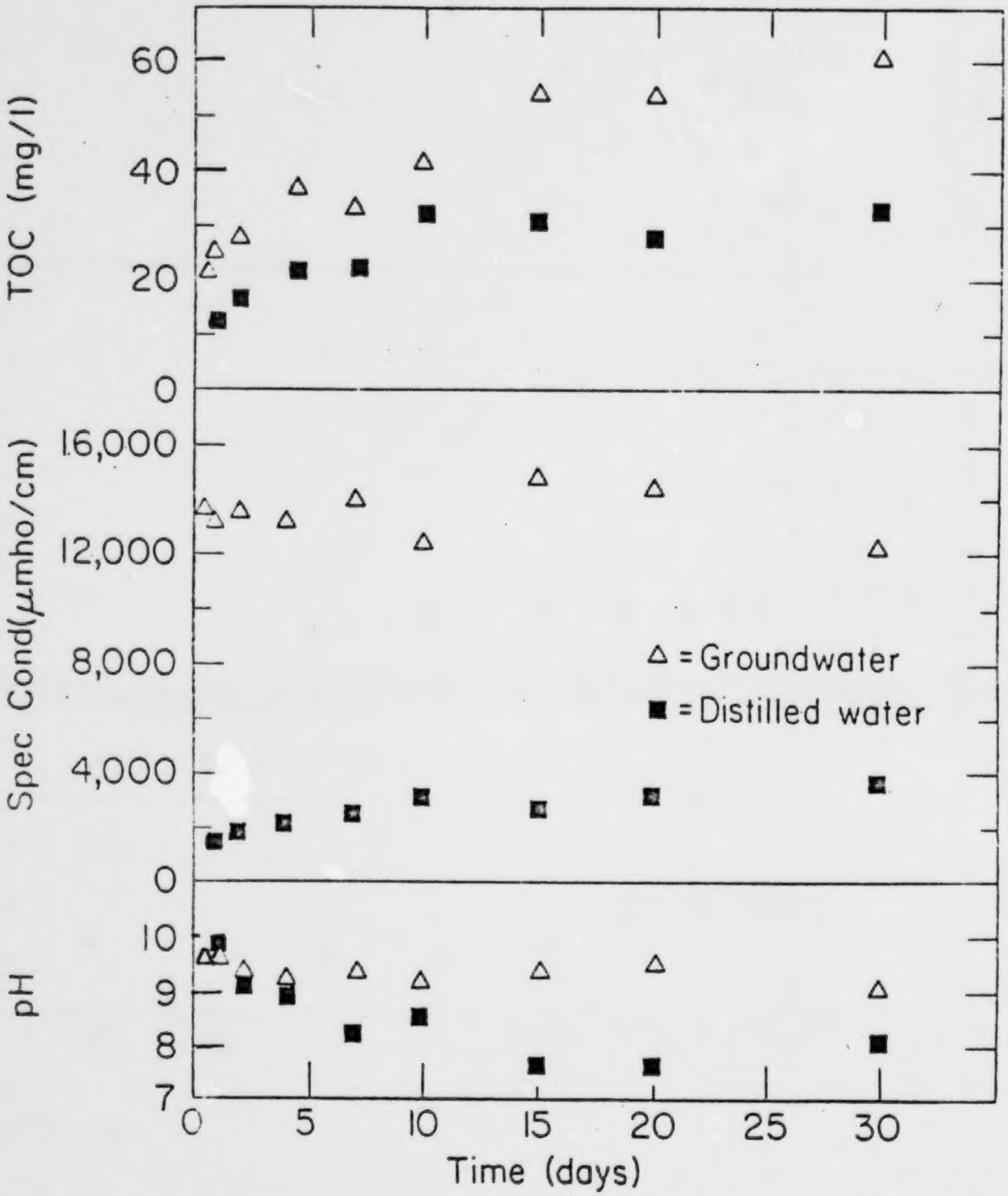
Figure 165



XBL 792-561

Groundwater batch experiments examining Type 1 spent shale at 80°C.

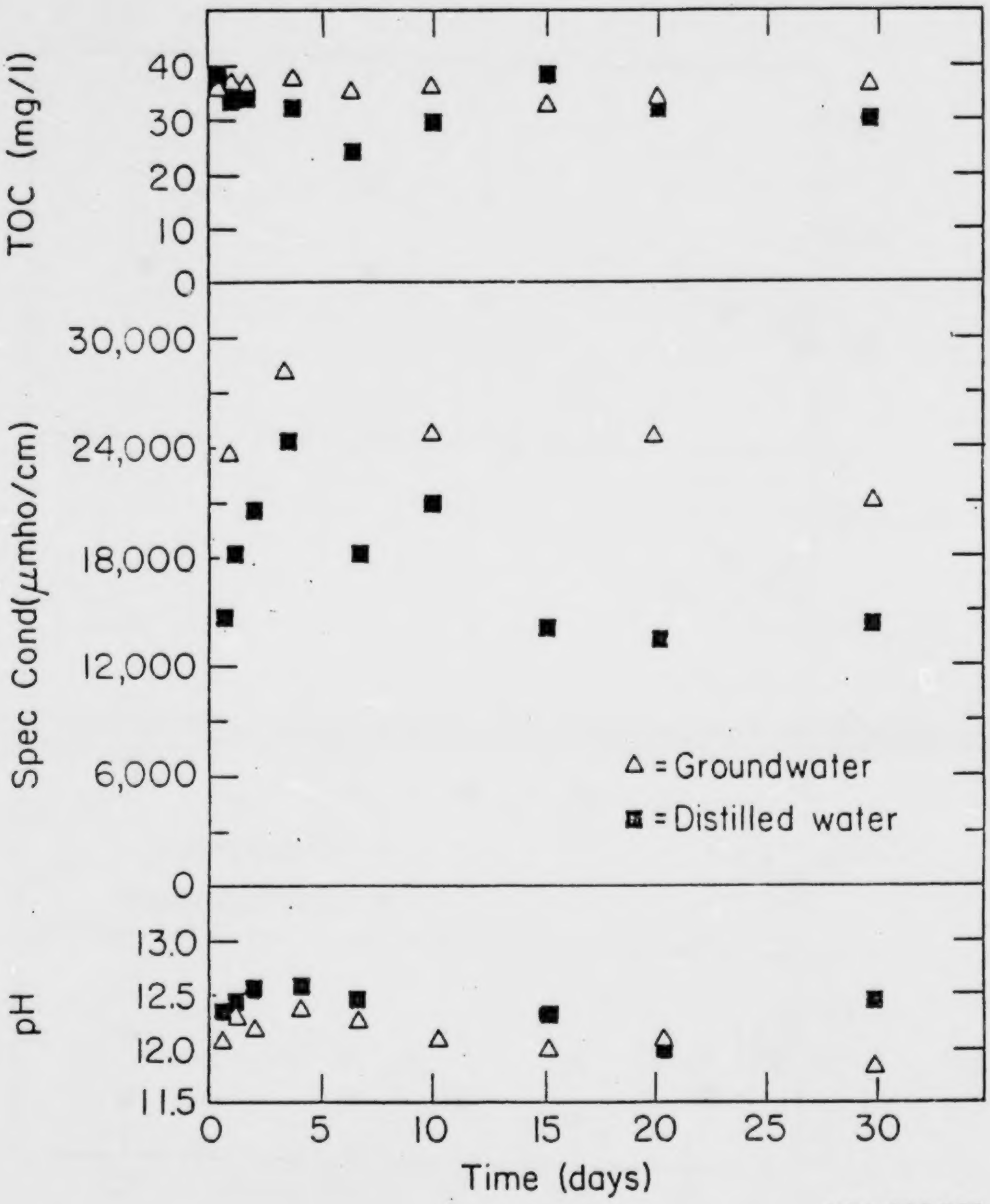
Figure 166



XBL 792-560

Groundwater batch experiments examining Type 2 spent shale at 80°C.

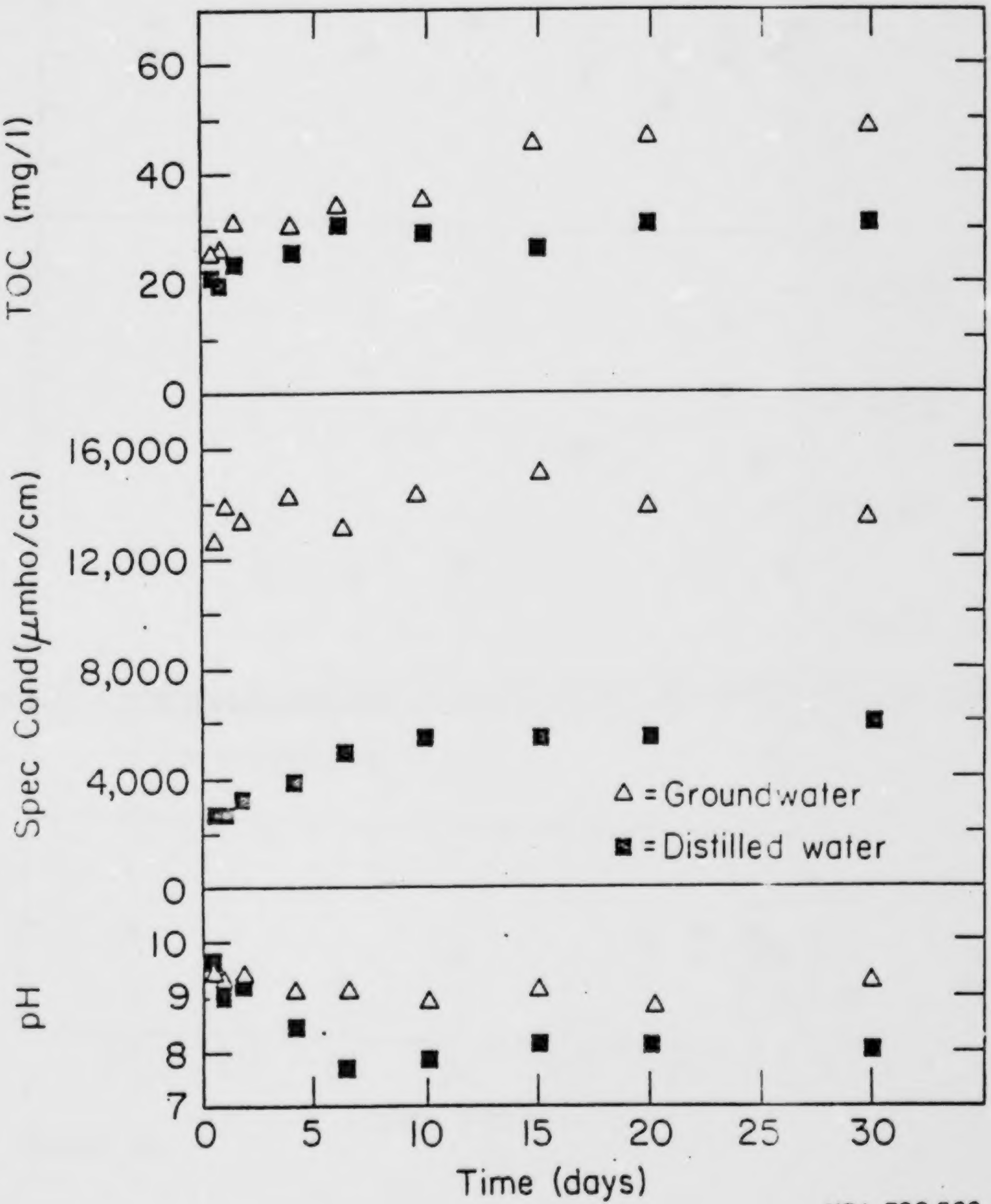
Figure 167



XBL 792-565

Groundwater batch experiments examining Type 3 spent shale at 80°C.

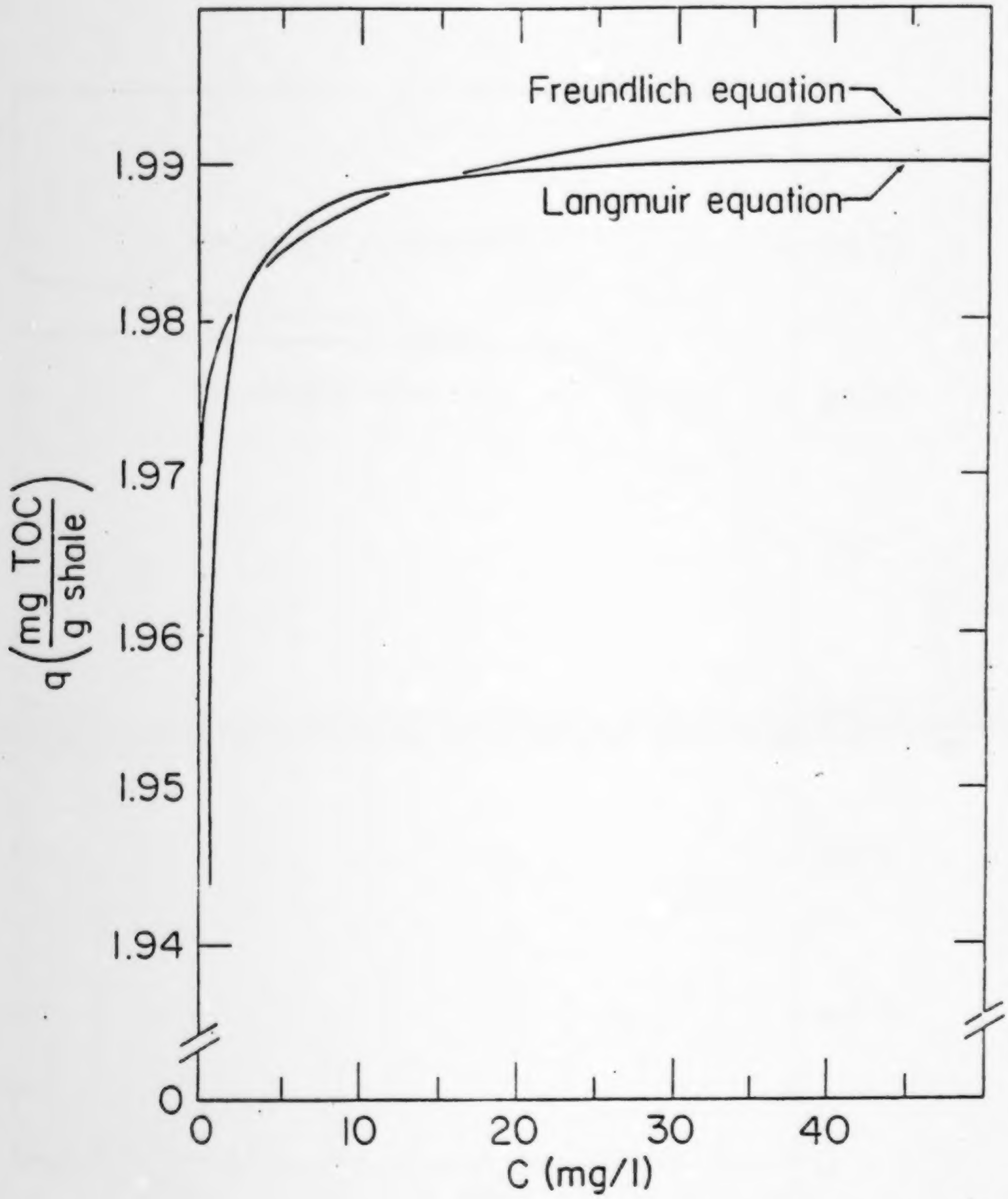
Figure 168



XB-L 792-566

Groundwater batch experiments examining Type 4 spent shale at 80°C.

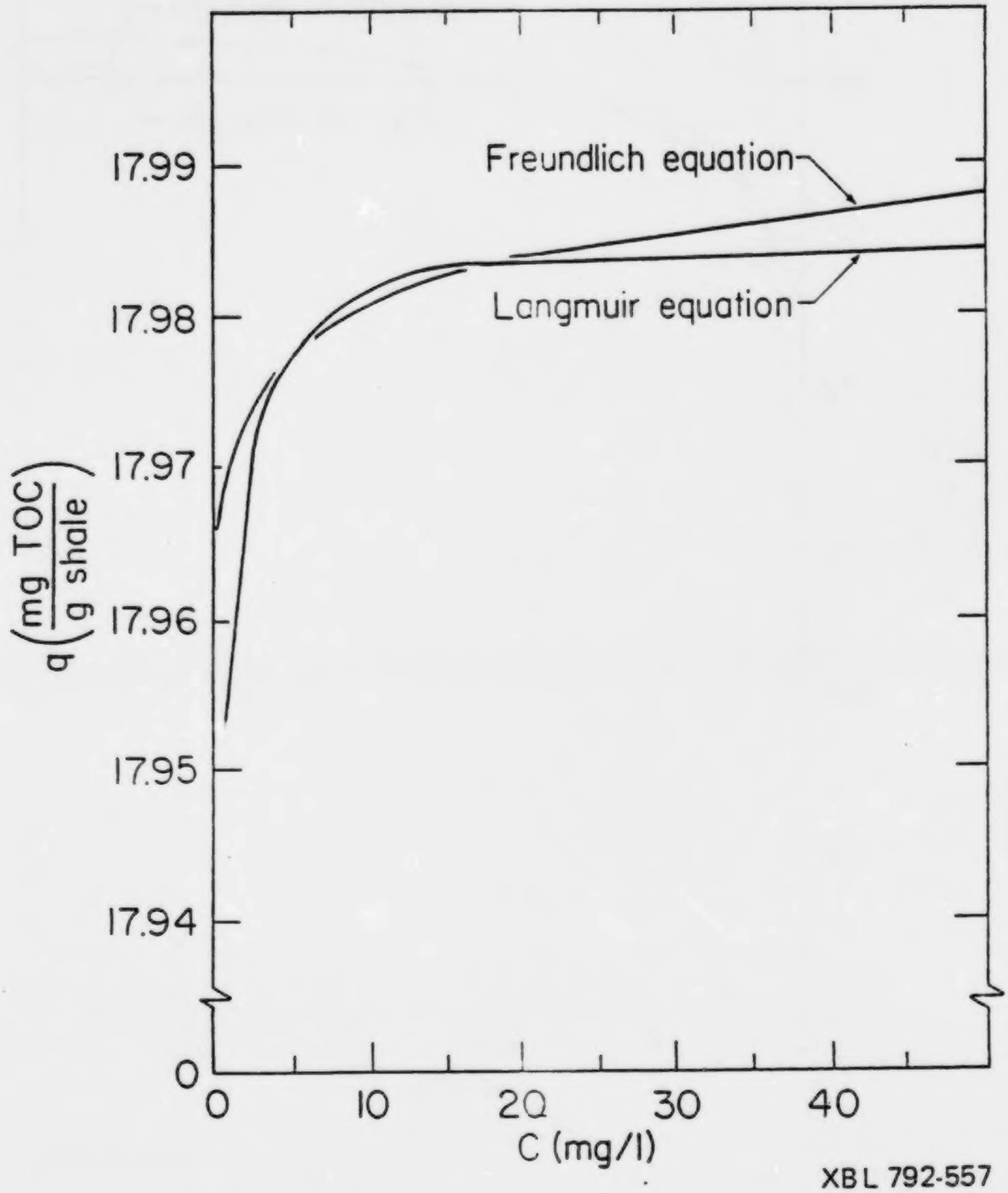
Figure 169



XBL 792-556

Plots of Langmuir and Freundlich equations for Type 1 spent shale examined with distilled water at 20°C.

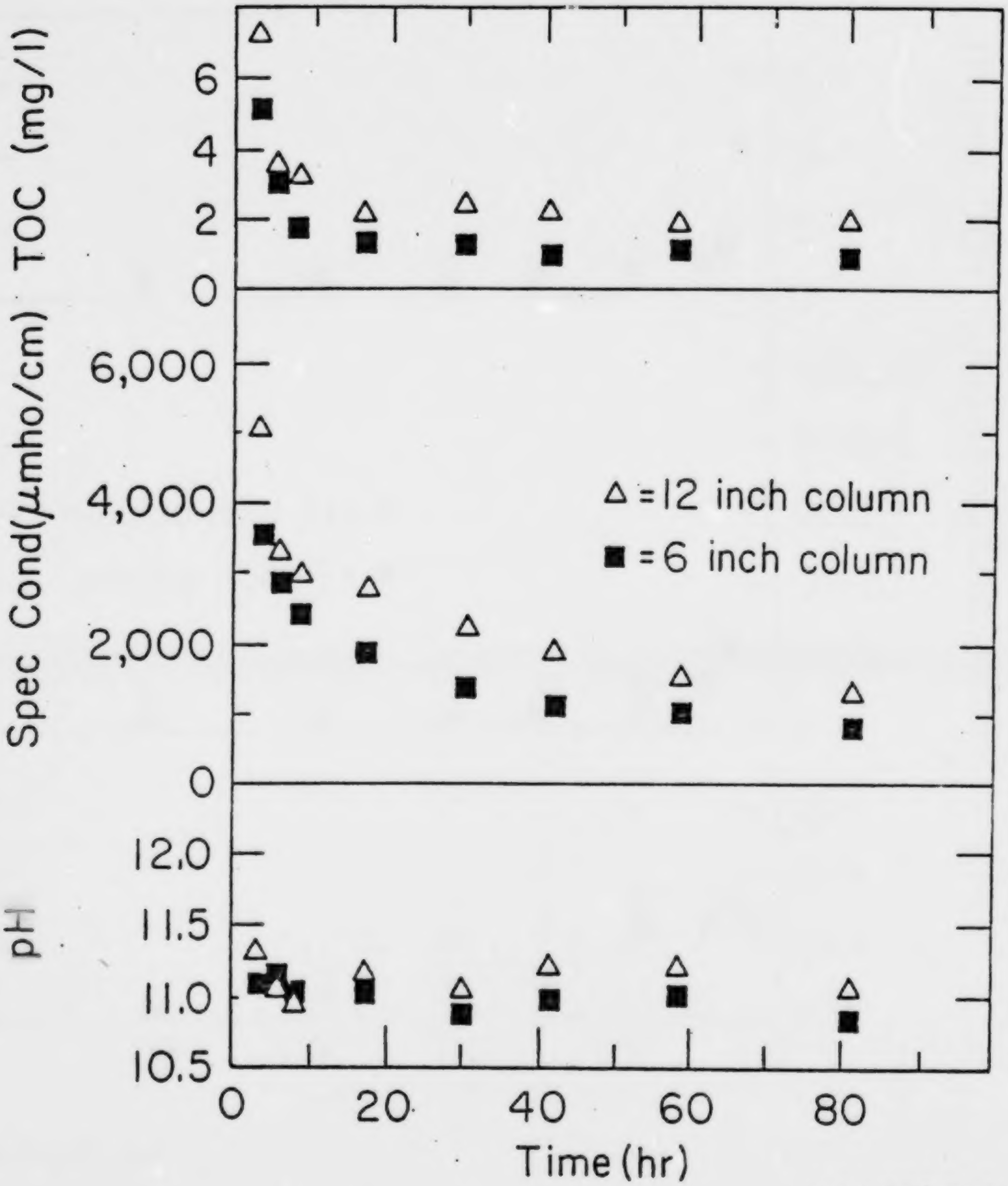
Figure 170



XBL 792-557

Plots of Langmuir and Freundlich equations for Type 2 spent shale examined with distilled water at 20°C.

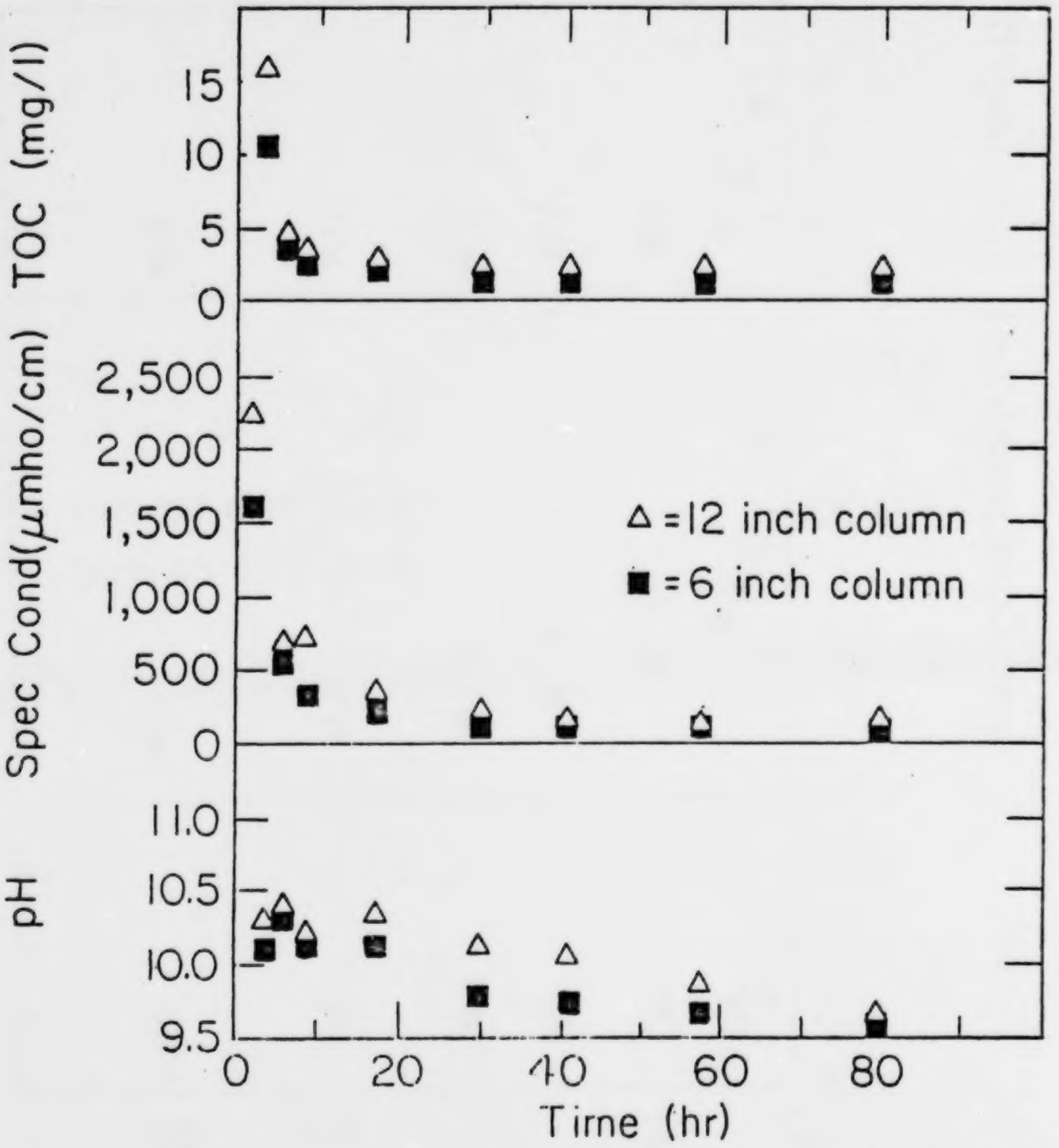
Figure 171



XBL 792-575

Continuous-flow column experiments examining Type 1 spent shale with distilled water.

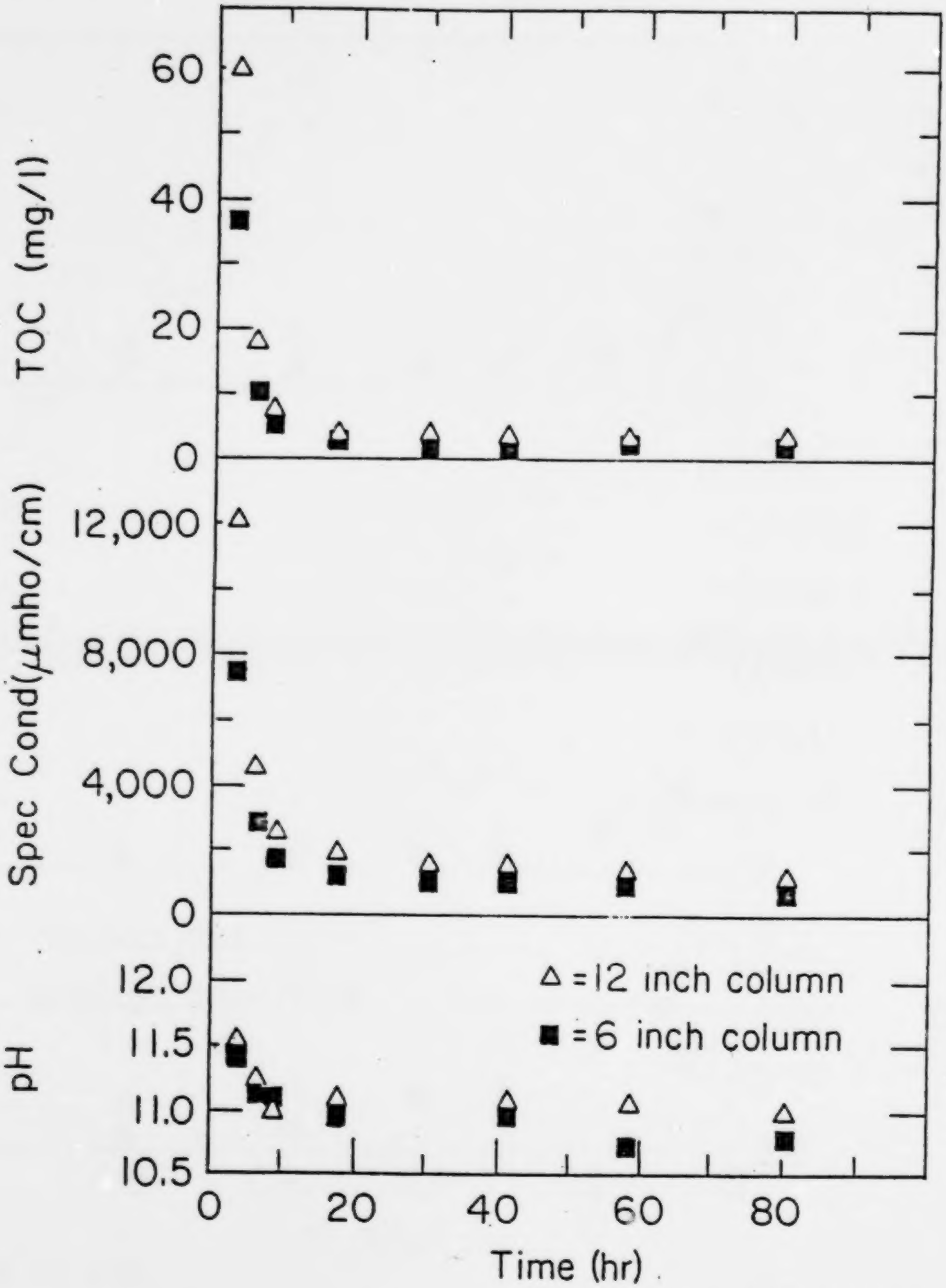
Figure 172



XBL 792-574

Continuous flow column experiments examining Type 2 spent shale with distilled water.

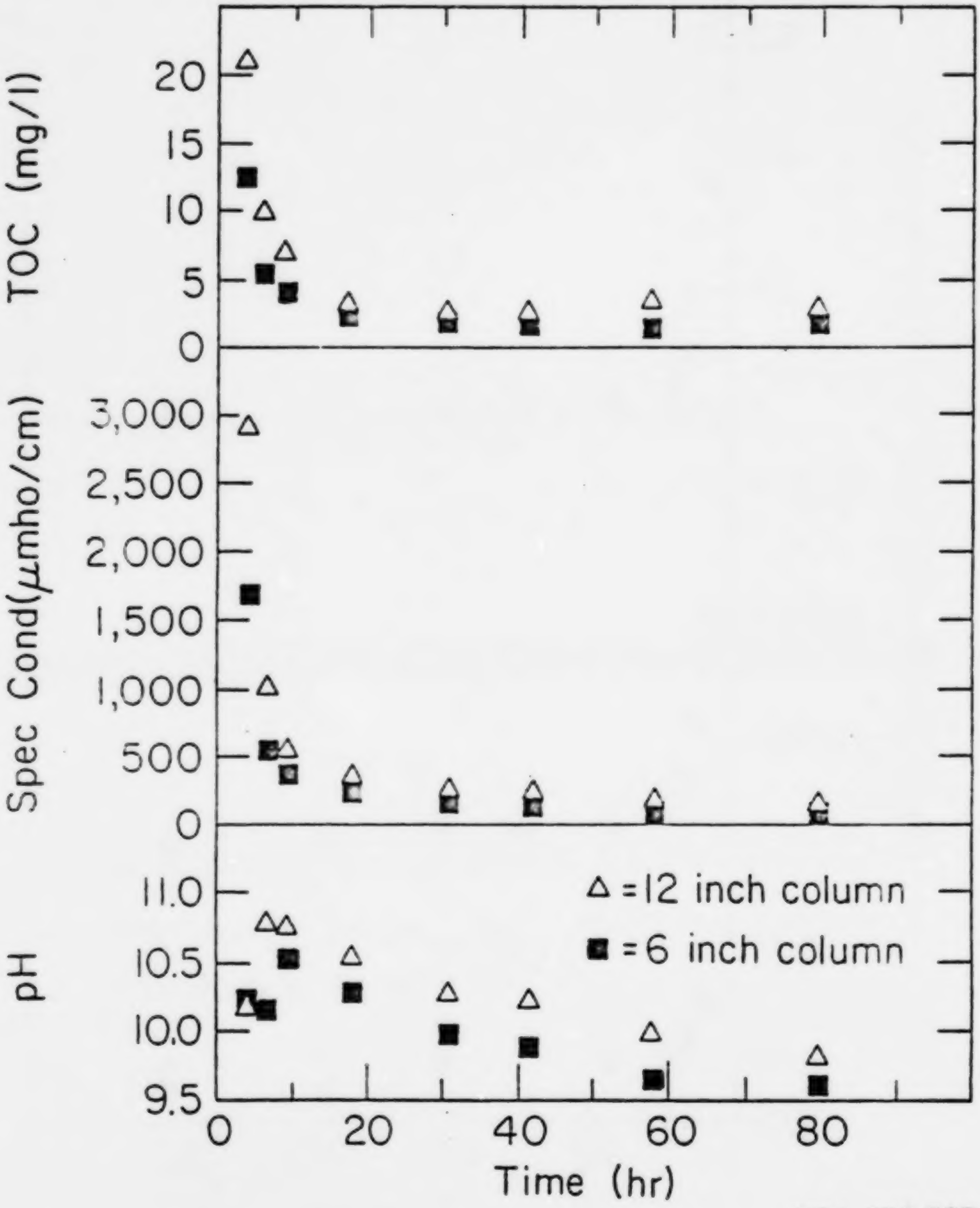
Figure 173



XBL 792-573

Continuous-flow column experiments examining Type 3 spent shale with distilled water.

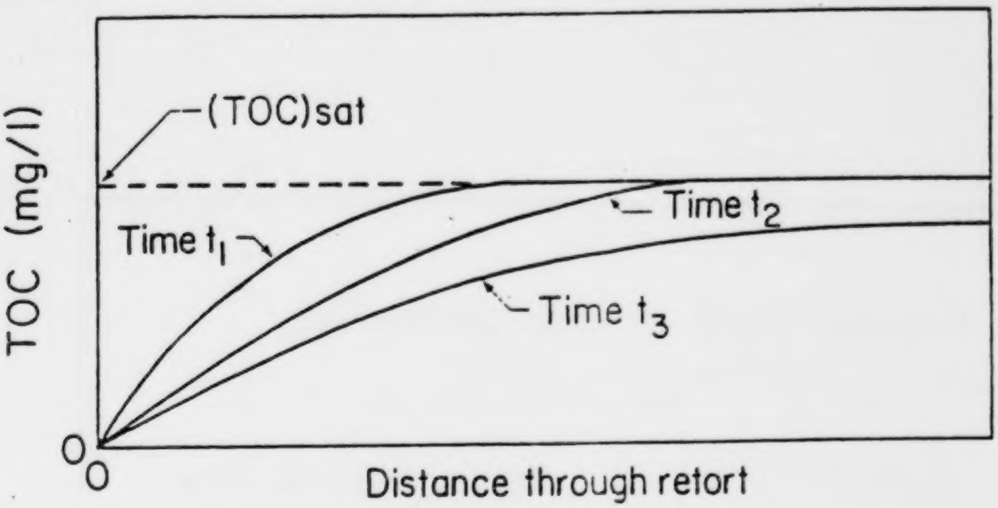
Figure 174



XBL 792-562

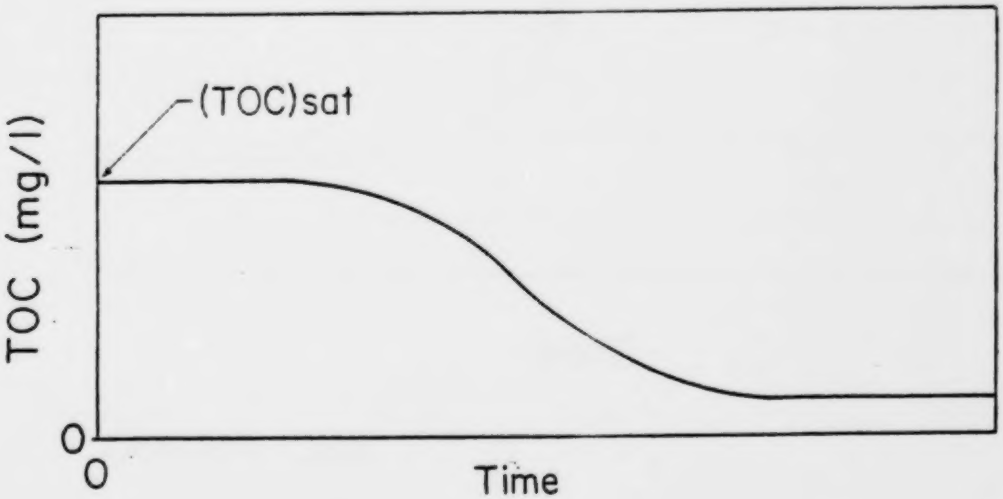
Continuous-flow column experiments examining Type 4 spent shale with distilled water.

Figure 175



TOC concentration profiles within a retort as a function of time.

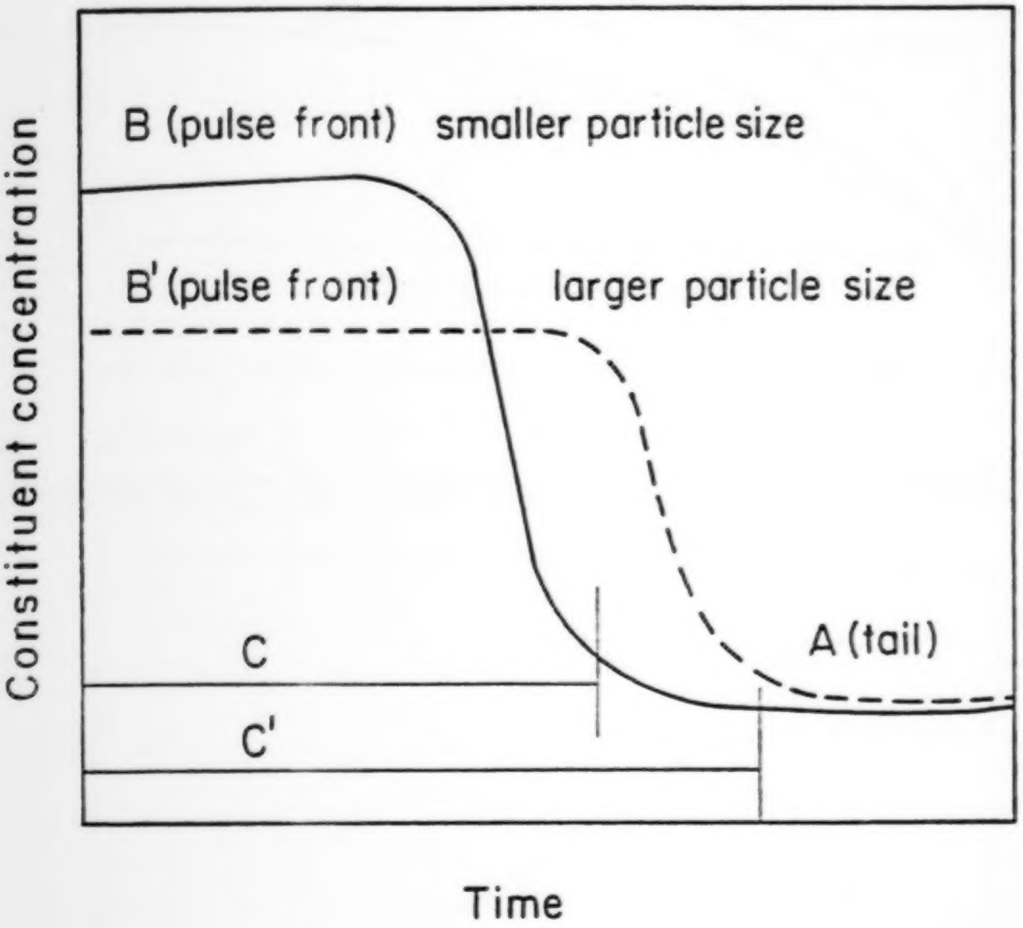
Figure 176



XBL 792-541

TOC concentration as a function of time in the effluent from a retort.

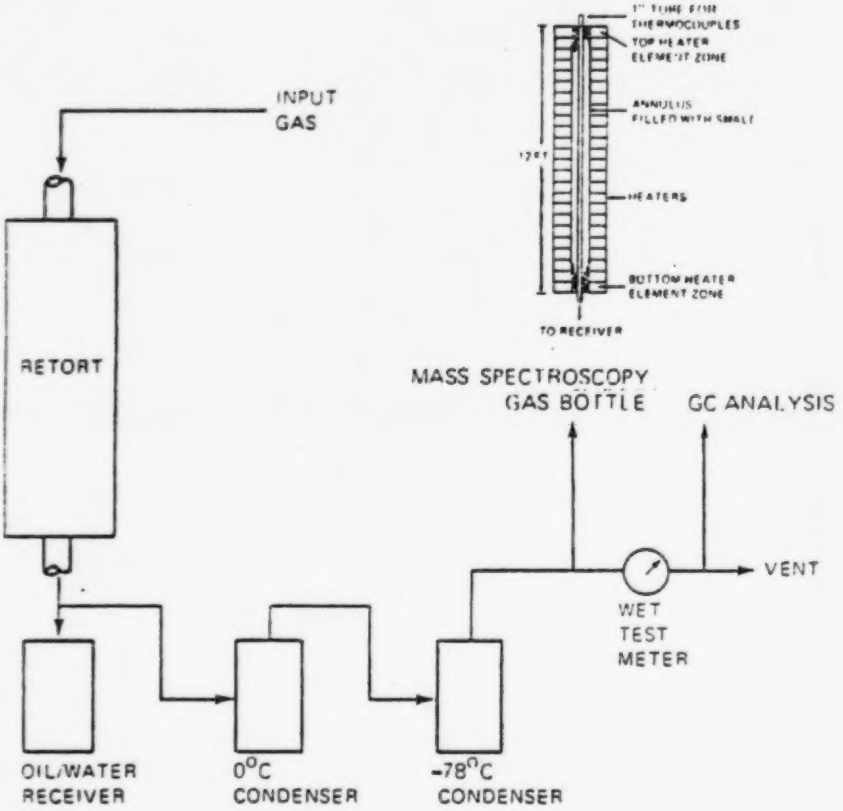
Figure 177



XBL 791-180

Schematic of effluent from an in-situ retort.

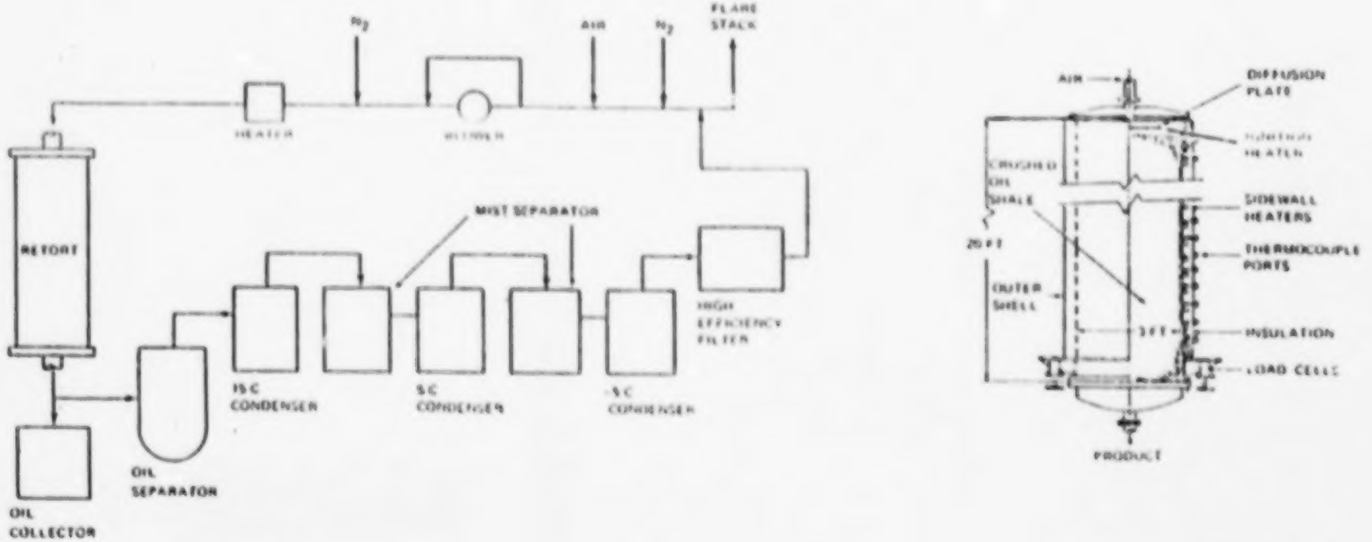
Figure 178



XBL 7810-11555A

Schematic of LETC's controlled-state retort.

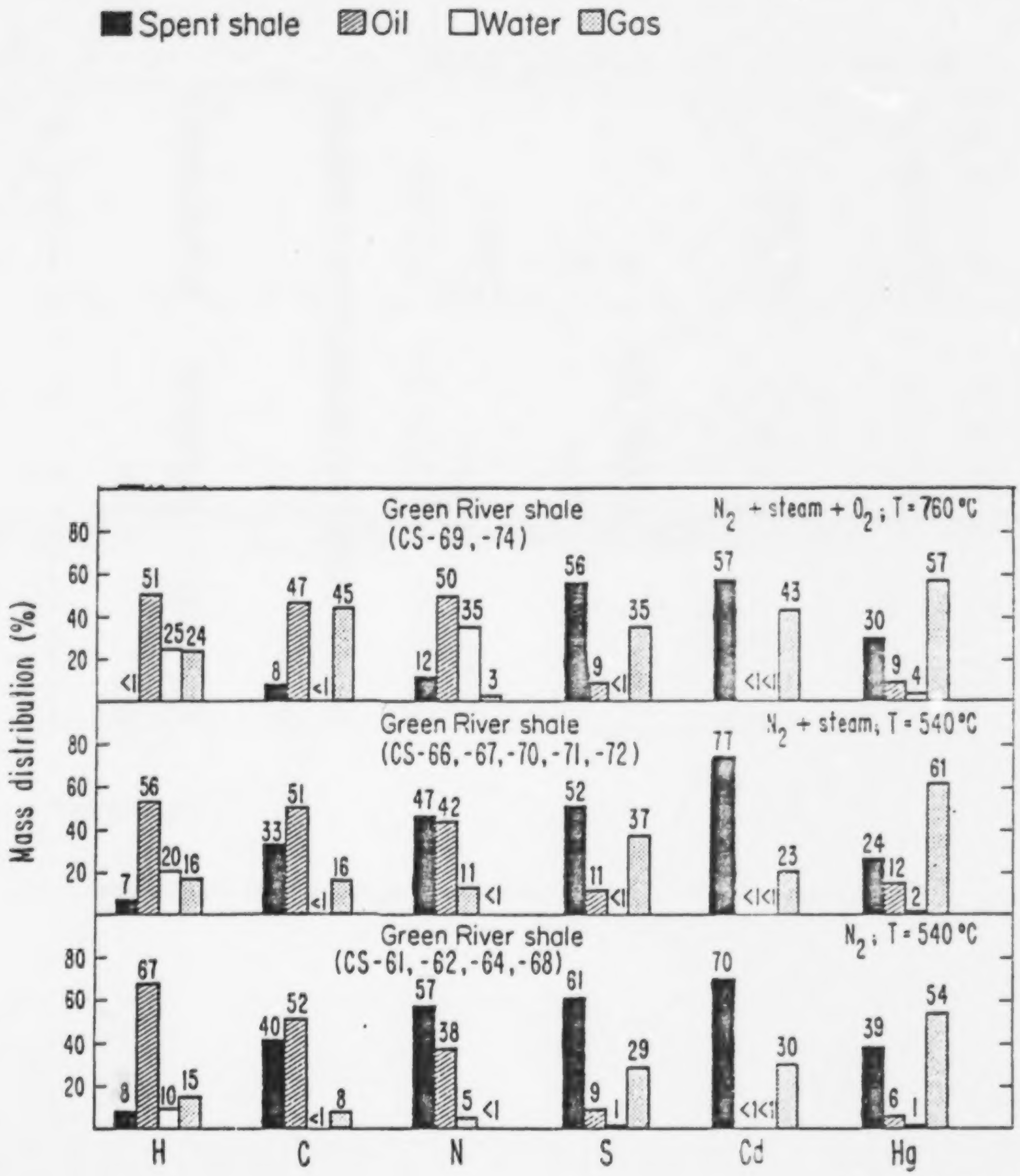
Figure 179



XBL 7810-11554

Schematic of LLL's 6000-kg simulated in-situ retort.

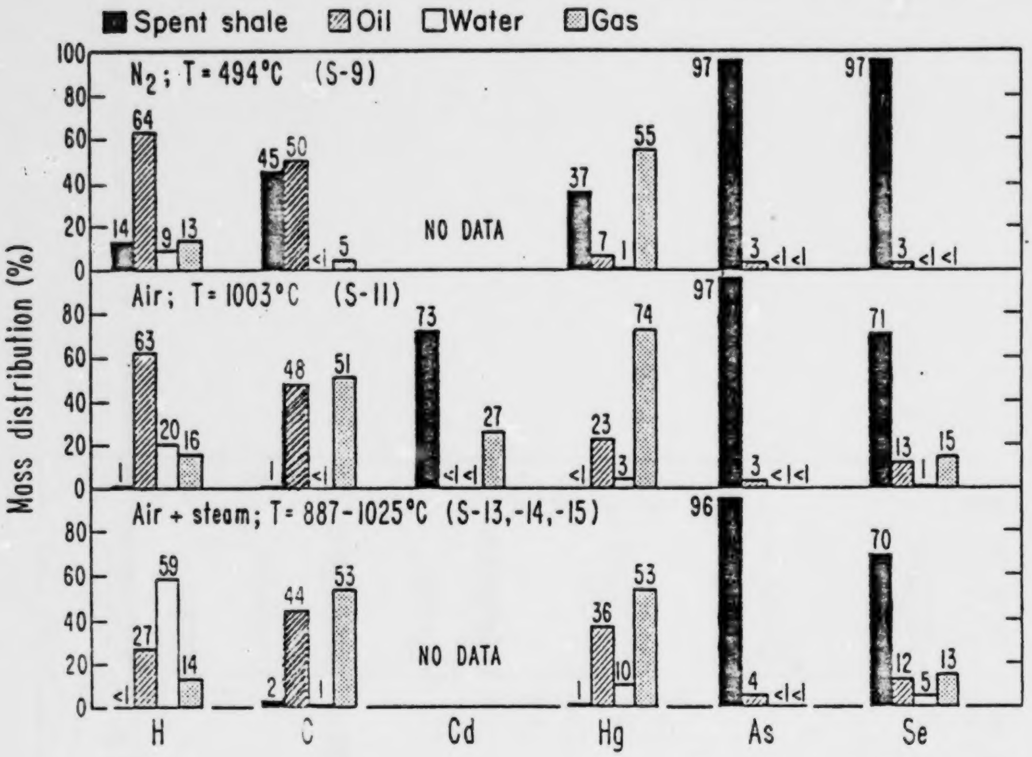
Figure 180



XBL 795-1651 B

Mass distribution patterns for Group 1 elements in LETC's controlled-state retort.

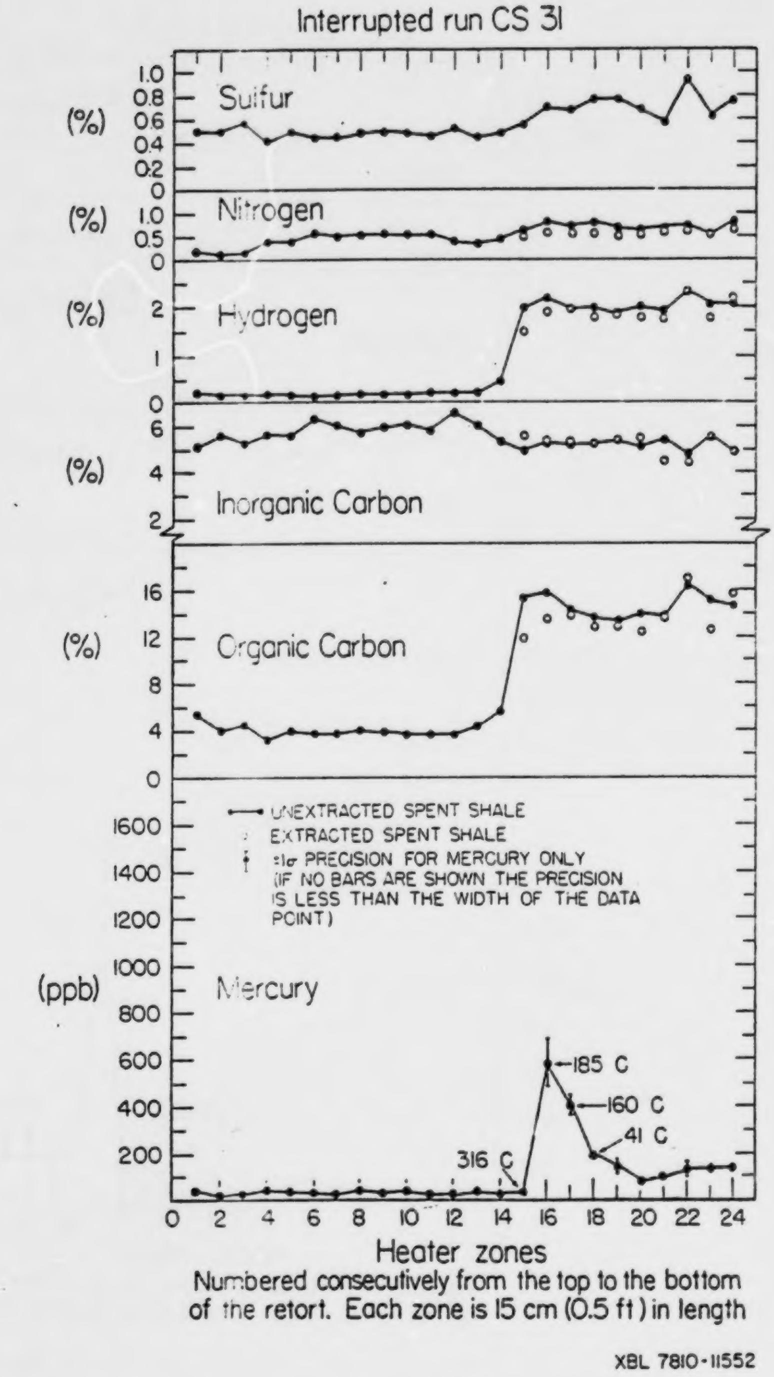
Figure 181



XBL 805-962

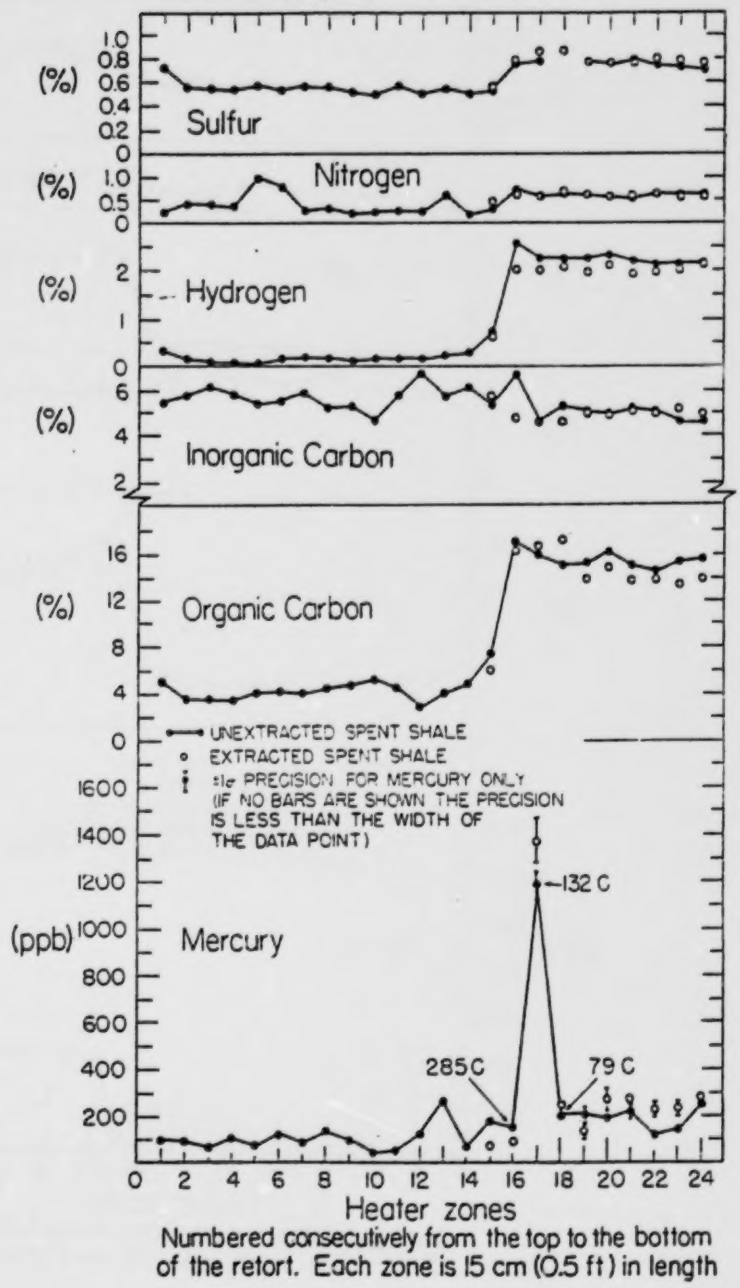
Mass distribution patterns for Groups 1 and 2 elements in LLL's 125-kg retort.

Figure 182



Variation in S, N, H, inorganic C, organic C, and Hg along the shale bed in incomplete runs CS-31 of LETC's controlled-state retort (shale particle size 10 - 19 mm).

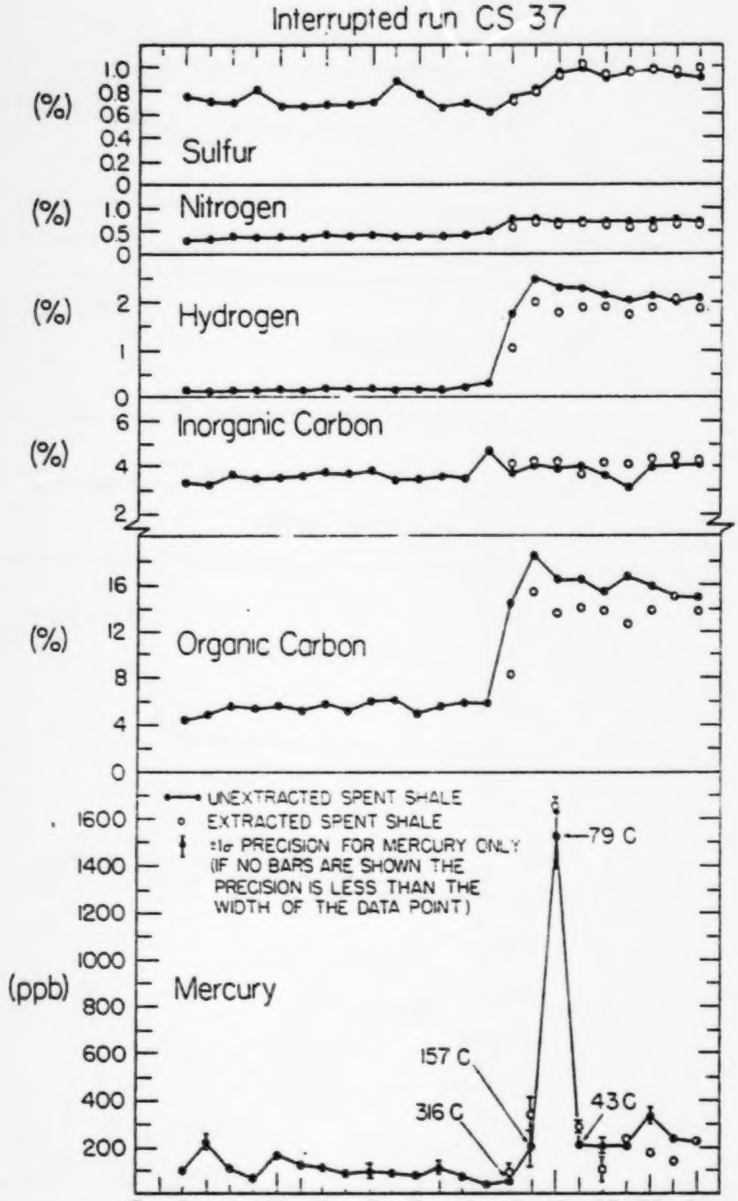
Figure 183



XBL 7810-11553

Variation of S, N, H, inorganic C, organic C, and Hg along the shale bed in incomplete runs CS-32 of LETC's controlled-state retort (shale particle size 3 - 10 mm).

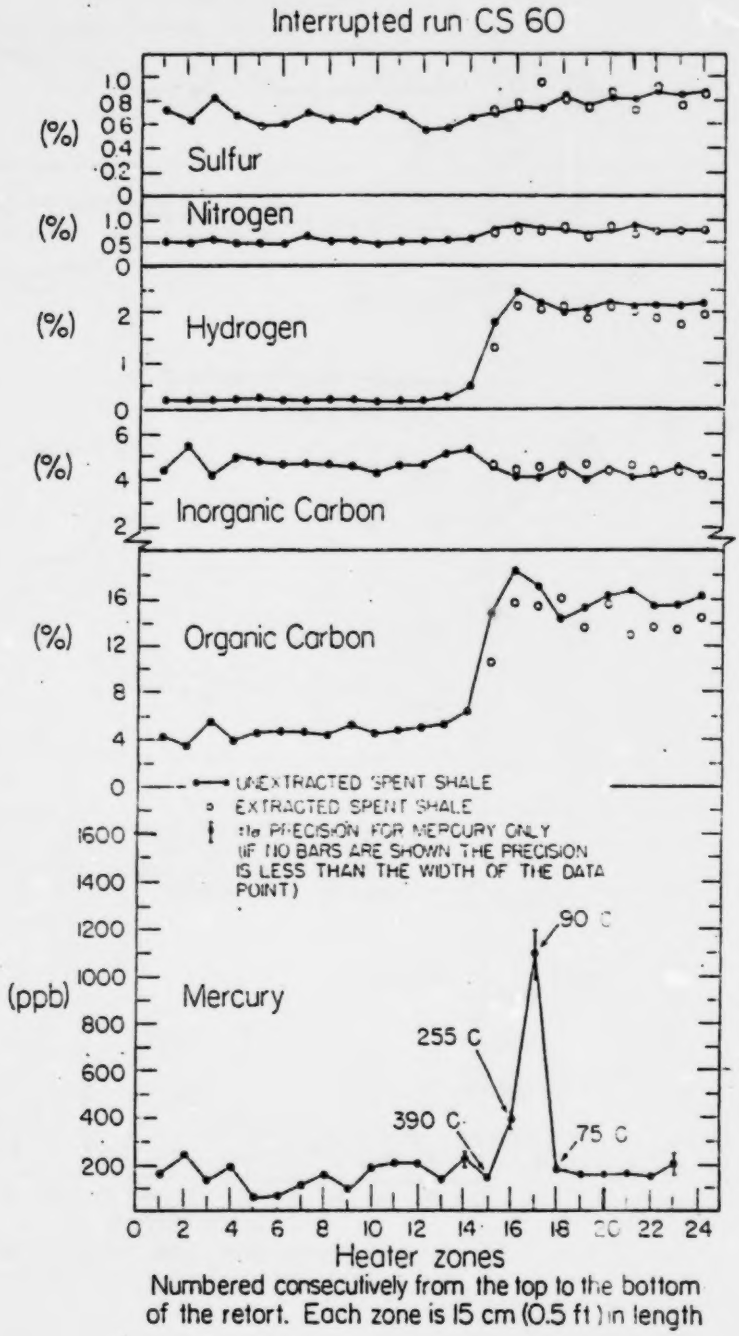
Figure 184



XBL 7810-11551

Variation in S, N, H, inorganic C, organic C, and Hg along the shale bed in incomplete runs CS-37 of LETC's controlled-state retort (shale particle size 3 - 13 mm).

Figure 185



XBL 7810-11550

Variation in S, N, H, inorganic C, organic C, and H along the shale bed in incomplete run CS-60 of LETC's controlled-state retort (shale particle size 3 - 13 mm).

Figure 186

SECTION 1
HYDROLOGY TABLES

DRILL HOLE COMPLETION SUMMARY
TRACT C-a AND VICINITY

Thirty On-Tract Holes

Drill Hole	Completion	Drill Hole	Completion
G-S 1	U&L	Am 4	P&A
G-S 2-3	U&L	CE - 701	Upper Aquifer Pumping Test
G-S 4-5*	U&L*	CE - 702	U&L
G-S 6	U&L	CE - 703	P&A
G-S 7	P&A	CE - 705-A	Upper Aquifer Pumping Test
G-S 8	Lower Aquifer Only	CE - 707	U&L
G-S 9	U&L	CE - 708	U&L
G-S 10	U&L	CE - 709	U&L
G-S 11	U&L	TO 1	U&L
G-S 12*	U&L*	TO 2	U&L
G-S 13	U&L	TO 3	Upper Aquifer Pumping Test
G-S 14	P&A	G-S D16	Lower Aquifer Pumping Test
G-S 15	U&L	G-S D17	Lower Aquifer Pumping Test
Am 2-A	U&L	G-S D18	Lower Aquifer Pumping Test
Am 3	U&L	G-S D19	Lower Aquifer Pumping Test

Five Off-Tract Holes

Drill Hole	Completion
G-S M1	U&L
G-S M2	U&L
G-S M3	U&L
G-S M4	U&L
G-S M5	AU

Totals

Completions in Upper and Lower Aquifers	22
Completions in Upper Aquifer Only	3
Completions in Lower Aquifer Only	5
Completions in Uinta Fm. Aquifers	1
Holes Plugged and Abandoned	4
Total Number of Holes	35

Am = Amoco Production Company
CE = Cameron Engineers, Inc.
G-S = Gulf-Standard (Indiana)
TO = The Oil Shale Corporation
U&L = Upper and Lower Aquifer Completions
P&A = Plugged and Abandoned
AU = Aquifers, Uinta Fm.

*Holes Temporarily Modified for Upper Aquifer Pumping Test

(R.B.O.S.C., Sept. 1977)

Table 1

Hole Numbers Geophysical Logs	C-1 (GS-1)	CH2-2 (GS2-3)	CH4-5 (GS4-5)	C-6 (GS-6)	CH-7 (GS-7)	C-8 (GS-A)	C-9 (GS-9)	C-10 (GS-10)	C-11 (GS-11)	C-12 (GS-12)	C-13 (GS-13)
Electric Log			x				x	x	x	x	x
Gamma Ray-Density							x	x	x		x
Formation Density	x		x								
Neutron Porosity											
Dual Induction-Lateral Log	x	x		x	x	x					
Acoustic											
Caliper (only)	x		x								
Neutron Density	x	x		x	x	x					
Sonic Log-Gamma Ray		x		x	x	x					
Temperature Log		x	x			x	x	x	x	x	x
3-Dimensional Velocity	x		x				x	x	x	x	x
Nuclear Log			x					x	x		x
Spinner Survey	x	x	x				x	x	x	x	x
Continuous Flow Meter				x		x					
Radioactive Tracer											
Geologic & Rock Structure (RQD)	x	x	x	x	x	x	x	x	x	x	x
Fischer Assay	x	x	x	x	x	x	x	x	x	x	
Trace Elements	x	x									
Nahcolite Analysis	x		x	x	x	x	x	x	x	x	
Seisviewer		x			x		x	x	x	x	
Water Quality Data											
Magnetic Inclinometer Survey											
Composite Log		x									
High Resolution Thermometer				x							
Alumina Assay											
Continuous Directional						x					
Shear Wave											
Compressional Amplitude											
Lithologic & Geolograph											

TABLE 2

C-14 (GS-14)	C-15 (GS-15)	CA-1 (TO-1)	CA-2 (TO-2)	CA-3 (TO-3)	CE	CE702	CE703	CE704C	CE705A (CE5)	CE706	CE707	CE708	CE709	CH2A (AM2A)	CH3 (AM3)	CH4 (AM4)	D-4
x	x																
x	x	x															x
			x	x	x	x	x	x	x	x	x	x	x	x		x	
						x	x	x	x	x	x	x	x				
		x	x	x	x	x	x	x	x	x	x	x	x	x		x	
																	x
		x				x							x		x	x	
x	x	x	x	x					x						x	x	x
x	x																
x	x																
x	x															x	x
		x	x	x	x		x	x	x	x	x			x	x	x	
																	x
x	x	x	x	x										x	x	x	
		x	x	x	x	x			x		x	x	x	x	x	x	
x	x																
x	x																
			x														
	x																
														x	x	x	
														x	x	x	

TABLE 2 (Cont.)

D-5	D-16	D-17	D-18	D-1	M-1	M-2	M-3	M-4	M-5	MDP 1	MDP 2-C	MDP 2-D
					x	x	x	x	x			
	x	x	x	x	x	x	x	x	x			
x												
										x	x	x
x					x	x	x	x		x	x	x
				x	x	x	x	x		x		
					x	x	x	x				
x					x	x	x	x		x	x	x
x										x	x	x
										x	x	
										x	x	
	x	x	x	x								
		x										
											x	
					x	x	x	x				

TABLE 2 (Cont.)

PUMPING TEST
SUMMARY
TRACT C-a

Pumping Hole	Average Transmissivity[1] Drawdown	Average Coefficient of Storage Drawdown	Average Transmissivity[1] Recovery	Average Coefficient of Storage Recovery
Upper Aquifer				
CE 705 A	--	--	25925 (2)	1.86×10^{-5} (1)
CE 705 A	17767 (3)	2.26×10^{-5} (2)	16990 (3)	3.31×10^{-5} (2)
CE 705 A	29348 (4)	4.51×10^{-5} (3)	24891 (4)	4.22×10^{-5} (2)
GS 4-5			5176 (1)	--
GS - 12	2381 (4)	1.06×10^{-4} (3)	7569 (2)	2.72×10^{-6} (1)
TO - 3	11769 (3)	9.9×10^{-5} (3)	20905 (2)	2.02×10^{-4} (2)
Lower Aquifer				
GS - 16	--	--	--	--
GS - 16	6458 (22)	1.19×10^{-6} (22)	58109 (11)	1.91×10^{-5} (11)
GS - 17	12218 (7)	1.09×10^{-4} (7)	19025 (10)	1.41×10^{-4} (8)
GS - 17	7547 (21)	6.21×10^{-5} (20)	24602 (18)	6.76×10^{-5} (18)
GS - 18	--	--	22843 (21)	5.38×10^{-5} (20)
GS - 19	7041 (22)	1.78×10^{-4} (21)	22690 (22)	1.25×10^{-4} (22)
GS - 19	14598 (19)	8.04×10^{-5} (18)	43461 (21)	1.65×10^{-4} (20)

( ) Number of observation holes

(R.B,C.S,C., Sept. 1977)

Table 3

PUMPING RATES & TIMES

Pumped Hole	Date Pump Turned On	Time Pump Turned On	Date Pump Turned Off	Time Pump Turned Off	Gallons Pumped per Minute	Total Time of Pumping (Min.)
Upper Aquifer						
CE-705-A	2/26/75	1230	3/ 8/75	0850	72	14180
CE-705-A	3/19/75	0905	3/22/75	1405	264	4620
CE-705-A	3/25/75	0825	4/ 1/75	1515	259	10490
GS-4-5	5/ 2/75	0945	5/19/75	0715	81.3	24330
GS-12	4/ 2/75	1045	4/13/75	0845	64.3	15720
TO-3	1/ 7/75	1000	1/28/75	1310	76.7	30430
Lower Aquifer						
GS-16	2/11/75 (Step Drawdown)	0945	2/11/75	1800	151 200 250	495
GS-16	2/15/75	1300	3/ 9/75	1230	123	31650
GS-17	1/ 6/75	1600	1/11/75	0928	275	6808
GS-17	1/18/75	1300	2/ 3/75	0830	275	22770
GS-18	5/21/75	1030	6/ 5/75	1100	174	21630
GS-19	4/ 8/75	1100	5/ 5/75	0030	667	38250
GS-19	5/20/75	1000	5/26/75	0655	667	8455

(R.B.O.S.C., Jul. 1975)

Table 4

PUMPING TEST
SUMMARY

Pumping Hole	Average Drawdown		Average Recovery	
	T	S	T	S
Upper Aquifer				
CE-705A	--	--	25925 (2)	1.86E-5 (1)
CE-705A	17767 (3)	2.26E-5 (2)	16990 (3)	3.31E-5 (2)
CE-705A	29348 (4)	4.51E-5 (3)	24891 (4)	4.22E-5 (2)
GS-4-5			5176 (1)	--
GS-12	2381 (4)	1.06E-4 (3)	7569 (2)	2.72E-6 (1)
TO-3	11769 (3)	9.9E-5 (3)	20905 (2)	2.02E-4 (2)
Lower Aquifer				
GS-16	--	--	--	--
GS-16	6458 (22)	1.19E-4 (22)	58109 (11)	1.91E-5 (11)
GS-17	12218 (7)	1.09E-4 (7)	19025 (10)	1.41E-4 (8)
GS-17	7547 (21)	6.21E-5 (20)	24602 (18)	6.76E-5 (18)
GS-18	--	--	22843 (21)	5.38E-5 (20)
GS-19	7041 (22)	1.78E-4 (21)	22890 (22)	1.25E-4 (22)
GS-19	14598 (19)	8.04E-5 (18)	43461 (21)	1.65E-4 (20)

( ) number of observation holes used in calculation

(R.B.O.S.C., Jul. 1975)

Table 5

PUMPING RATES & TIMES

Pumped Hole	Date Pump Turned On	Time Pump Turned On	Date Pump Turned Off	Time Pump Turned Off	Gallons Pumped per Minute	Total Time of Pumping (min.)
Upper Aquifer						
CE 705-A	2/26/75	1230	3/08/75	0840	72	14180
CE 705-A	3/19/75	0905	3/22/75	1405	264	4620
CE 705-A	3/25/75	0825	4/01/75	1515	259	10490
G-S 4-5	5/02/75	0945	5/19/75	0715	81.3	24330
G-S 12	4/02/75	1045	4/13/75	0845	64.3	15720
TO 3	1/07/75	1000	1/28/75	1310	76.7	30430
Lower Aquifer						
G-S 16	2/11/75 (Step Drawdown)	0945	2/11/75	1800	151	495
G-S D16	2/15/75	1300	3/09/75	1230	123	31650
G-S D17	1/06/75	1600	1/11/75	0928	275	6808
G-S D17	1/18/75	1300	2/03/75	0830	275	22770
G-S D18	5/21/75	1030	6/05/75	1100	174	21630
G-S D19	4/08/75	1100	5/05/75	0030	667	38250
G-S D19	5/20/75	1000	5/26/75	0655	667	8455

(R.B.O.S.C., Sept. 1977)

Table 6

AQUIFER CHARACTERISTICS

AQUIFER CHARACTERISTICS	AQUIFER	CORE HOLE CE 701	CE 702	CE 703	CE 704c	CE 705A	CE 706	CE 707	CE 708	CE 709	U.S.B.S.#2	
1. Aquifer Depth (feet)	Mahogany Lower	220-310 920-1020	50-440 1505-1540	250-400 660-720	620-780 1480-1600	220-440 1060-1100	130-840 1120-1320	70-560 1040-1350	110-360 800-880	120-510 580-1350	557-1450 1673-2075	
2. Static Water Level	Mahogany	200	65	40	70	35	150	225	70	50	250	
	Mahogany + Lower	320 7	68	240	180	60	335	566	150	90	275	
	Lower	380' 325	70	280	190	160	400	600	280	120	600	
3. Production Rate (gpm)	Mahogany Maximum	50 120 285 65	200 1000 655 560	45 ---	300 880	340 160 713	400 600	40 240	70 470	760 780	400 510	
4. Specific Capacity (gpm/ft)												
Recovery Test	Mahogany & Lower		5 10	.2			1.5 15	.2	1 4	20	.5	
Packer Test	Mahogany Lower	1 2		2		2.7						
5. Transmissibility (gpd/ft)	Mahogany Lower	2000 4000	20000 20000	1000 4000	2000 15000	3000 10000	4000 20000	1000 3003	1500 3000	25000 30000	5000 500	} representative values
Recovery Test												
Drilling (t')	Mahogany & Lower		36000 27000	500	2200	10000	3000 20000	900	3800 5400	19000	3400	
Drilling (t/t')	Mahogany & Lower		27000 14000	270	1500	6600	1500	600	1403 3400	13003		
Packer Test	Mahogany Lower	660 2000		3700 9200		3000 1600			1100 1900		380	
Constant Drawdown	Mahogany Lower	500 1500				430 600						
Specific Capacity	Mahogany & Lower	2000 4000	10000 20300	600 4000		5400 ---	3000 30000	400	2000 8000	40000	1000	
6. Coefficient of Storage *												
Packer Tests	Mahogany Lower	2×10^{-1} * 3 *		1×10^{-24} * 10 *		1×10^{-2} * 10 *			2×10^{-2} * 5x10 *			
Constant Drawdown	Mahogany Lower	140 * 50 *				16000 * 10000 *						

* All values of coefficient of storage are not reliable due to insufficient data

Table IV

(Wright Water Engineers, Inc., Dec. 1973)

Table 7

AQUIFER CHARACTERISTICS

CORE HOLE		2A	3	4
Aquifer Interval (approximate)	Upper	400-1000	250-400	750-950
	Lower	1500-1650	550-600 800-950	1150-2000
Static Water Level	Upper	425 445	42 55	448
	Combined	537 558	255 259	466 463
	Lower	608 597	270 269	488
Production Rate Pump Test (gpm)	Upper	277	100	130
	Lower	255	289	265
Specific Capacity (gpm/ft)	Upper		0.2	
Drilling	Combined	0.5	10	
Pump Test	Upper	2	0.4	1
	Lower	5	10	6
Transmissivity (gpd/ft)	Upper	3200	700	250
Drilling	Combined	8100	47500	---
Pump Tests				
Drawdown	Upper	4600	---	---
Recovery		5200	400	900
Drawdown	Lower	20000	20000	17500
Recovery		17000	15000	15000
Specific Capacity	Upper	4000	800	1500-1800
Pump Tests	Lower	12000	20000-22000	16000
Distance	Upper	---	---	---
Drawdown	Lower	---	---	16000
Drawdown Observation Hole No. 2A	Lower	---	---	15000
Drawdown Recovery		---	---	17500
Coefficient of Storage (ratio)	Lower	---	---	1×10^{-5}
Observation Hole 2A Volume	Lower	---	---	2×10^{-5}
	Upper	1×10^{-4}		

(Wright Water Engineers, Inc., Dec. 1973)

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Table 8

RIO BLANCO OIL SHALE PROJECT

COREHOLE HYDROLOGIC COMPLETION SUMMARY

HOLE NUMBER	CH 1	CH 2-3	CH 4-5	CH 6	CH 7	CH 8	CH 9	CH 12
AQUIFER INTERVALS								
Upper	420-450	235-475	202-650	180-630	200-380	460-720	300-630	540-890
Lower	910-1404	900-1424	1180-1663	1300-1780	690-1200	1150-1600	1080-1600	1280-1800
UPPER AQUIFER DATA								
Static Water Level	240	120	40	40	10	345	320	450
Production GPM	65	180	360	300	35	90	100	60
Transmissivity GPD/Ft.	I.D.	3000	6800	175-19,800	40-770	I.D.	I.D.	110-7930
Specific Capacity GPM/Ft.	.43	1.7	3.6	.50	.46	I.D.	.5	.34
Avg. Spec. Cond. µ mhos/cm.	1000	1160	1210	1200	1000	1100	1520	1700
Avg. Temperature °F	57	59	60	62	57	59	58	59
Avg. pH	6.7	7.0	6.7	7.6	7.1	7.0	6.7	7.0
COMBINED AQUIFER DATA								
Static Water Level	270	180	65	200	390	520	370	500
Production GPM	170	490	850	530	240	210	300	275
Transmissivity GPD/Ft.	150-170	550-1800	11,800	365	320-1670	400-1200	240-1200	600-7300
Special Capacity GPM/Ft.	.18	.05	6.4	.24	1.1	.04	.63	1.5
Avg. Spec. Cond. µ mhos/cm.	2055	2760	2850	2840	1300	2250	2600	2660
Avg. Temperature °F	59	71	76	75	62	64	69	70
Avg. pH	6.8	7.4	7.5	7.9	6.9	7.5	7.4	7.7
HOLE DATA								
Date Started	Aug. 10	July 27	Aug. 10	July 3	July 26	June 28	Aug. 28	Sep. 3
Date Completed	Aug. 24	Aug. 10	Sep. 1	July 23	Aug. 7	July 19	Sep. 12	Sep. 15
Total Depth	1404	1424	1663	1781	1200	1616	1600	1300

Note: I.D. = Insufficient Data

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(R.B.O.S.C., 1974)

Table 9

Table 10

AQUIFER CHARACTERISTICS FROM DRILLING PROGRAM

HOLE NUMBER		GS-1	GS-2-3	GS-4-5	GS-6	GS-7	GS-8	GS-9	GS-10	GS-11	GS-12	GS
AQUIFER INTERVAL feet	Upper	260-450	180-470	220-650	180-630	200-400*	400-720	410-610	640-820	670-910	550-620	510
	Lower	900-1230	920-1200	1050-1400	1300-1780	1000-1200	1060-1460	1070-1240	1380-1600	1350-1440	1280-1433	1280
STATIC WATER LEVEL feet	Upper (as of 1-15-75)	245	117	75	10	(10)	(340)	323	340	478	407	38
	Composite	270	180	65	50	250	520	370	350	580	560	51
	Lower (as of 1-15-75)	580	208	65	51	--	623	487	360	691	619	54
PRODUCTION RATE gpm (Maximum)	Upper	100	200	560	375	80	70	140	280	125	100	12
	Combined	160	500	865	575	250	250	300	455	310	300	37
APPARENT SPECIFIC CAPACITY gpm/ft.	Upper	.43	1.7	3.6	.50	.46	--	.5	1.6	3.7	.34	
	Combined	.18	.85	6.4	.24	1.1	.84	.63	.24	1.2	1.5	
APPARENT TRANSMISSIVITY T, gpd/ft.	Upper	--	3000	6800	19,800	770	--	--	2960	5900	7900	520
	Combined	170	1800	11,800	375	1670	1200	1200	570	1640	7300	330
AVERAGE SPECIFIC CONDUCTANCE umhos/cm	Upper	1000	1160	1800	1200	1000	1100	1520	1160	980	1700	110
	Combined	2055	2760	2850	2840	1500	2250	2800	4500	3700	3100	280
AVERAGE TEMPERATURE °F	Upper	57	59	60	59	57	59	58	61	58	59	5
	Combined	59	71	76	75	62	64	69	79	71	70	7
AVERAGE pH	Upper	6.7	7.0	6.7	7.6	7.0	7.0	6.7	7.1	7.0	7.0	
	Combined	6.8	7.4	7.5	7.9	7.0	7.5	7.4	8.1	8.1	7.7	
AVERAGE DISSOLVED SOLIDS milligram/liter	Upper	1350	1000	1000	840	800	720	1300	1250	1700	2000	137
	Combined	3440	2300	1900	3600	1280	1400	2100	1900	2940	3000	230

*Representative value

**E logs

(R.B.O.S.C., Oct. 1974/Feb. 1975)

CORE HOLE		CE-701	CE-702	CE-703	CE-704c	CE-705A	CE-706	CE-707	CE-708	CE-709	U.S.B.M. #2	AM-2a	AM-3
AQUIFER INTERVAL (ft)	Upper	220-310	350-440	690-740	620-780	220-440	130-840	200-560	150-300	120-510	957-1450	420-980	270-4
	Lower	940-1020	1375-1540	1250-1315	1480-1600	820-1100	1120-1320	1040-1360	800-880	980-1260	1673-2075	1510-1610	750-5
[illegible] WATER LEVEL	Upper (as of 1-15-75)	156	53	(49)	70	(35)	150	274	55	53	250	419	45
	Composite	320	68	240	183	63	335	566	150	90	275	537	255
	Lower (as of 1-15-75)	(380)	6	(280)	190	(160)	400	545	272	130	600	606	283
[illegible] RATE ([illegible])	Upper	50	200	45	300	340	400	40	70	700	400	277	100
	Combined	285	655	--	890	730	600	240	470	780	510	255	239
[illegible]	Upper	(1)	5	.2	--	--	1.5	.2	1	20	--	--	
	Combined	(2)	10	(2)	--	(2.7)	15	-	4	--	.5	.5	10
[illegible] TRANSMISSIVITY [illegible]	Upper	2000*	36,000	1000*	2200	3000	3000	960	3800	19,000	5000	3200	700
	Combined	4000*	27,000	500	--	10,000	20,000	--	5400	--	500	8100	47,50
[illegible] SPECIFIC [illegible]	Upper	1100	900	2800	1000	1000	1250	1300	1100	1100	1000	1300	1100
	Combined	1500	3000	2800	2600	1700	1400	2500	2000	1150	1200	2600	5000
AVERAGE TEMPERATURE	Upper	--	50	--	--	54	--	52	57	51	--	60	55
	Combined	--	72	--	--	56	--	53	63	54	--	72	65
AVERAGE pH	Upper	8.0	7.9	8.4	8.6	7.4	7.5	8.0	8.0	7.7	8.2	8.4	8
	Combined	8.3	8.1	8.3	8.4	8.1	8.0	7.9	8.0	7.8	8.1	8.4	8
AVERAGE DISSOLVED [illegible] mg per liter	Upper	1050	800	1200	830	800	930	1000	1000	900	600	1000	70
	Combined	1590	2200	1200	2400	1600	2200	1700	1900	900	650	1400	39

*[illegible]

(Wright Water Engineers, April 1975)

Table 10

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(Continued)

HOLE NUMBER		GS-14	GS-15	GS-M1	GS-M2	GS-M3	GS-M4	GS-016	GS-017	GS-018	GS-019
AQUIFER INTERVAL feet	Upper	680-780	600-700	600-830	360-1160	100-1000	840-960	580-620	220-310	350-440	220-440
	Lower	1200-1400*	1300-1400	1360-1500	1980-2030	1450-1650	1720-1990	128-1430	940-1020	1375-1540	960-1100
STATIC WATER LEVEL feet	Upper (as of 1-15-75)	(330)	279	643(50)**	241	22	487	--	--	--	--
	Composite	410	320	700	320	90	540	--	--	--	--
	Lower (as of 1-15-75)		334	798	348	128	535	--	--	--	--
PRODUCTION RATE gpm (Maximum)	Upper	40	100	20	440	1020	200	190	120	1060	360
	Combined	300	500	150	510	1300	260	230	85	415	660
APPARENT SPECIFIC CAPACITY gpm/ft.	Upper	.43	2.8	.3	2.2	8.2	.9	--	--	--	--
	Combined	3.3	.66	.4	--	3.3	--	--	--	--	--
APPARENT TRANSMISSIVITY t_1, gpd/ft.	Upper	1900	6400	510	3100	12,000	1200	--	--	--	--
	Combined	5300	1320	410	--	8800	--	--	--	--	--
AVERAGE SPECIFIC CONDUCTANCE umhos/cm	Upper	1100	1100	1200	1000	1040	1500	1200	1200	2200	950
	Combined	2950	3400	3400	8200	16,500	3840	4200	1500	4800	1750
AVERAGE TEMPERATURE °F	Upper	58	59	54	61	54	61	56	56	58	53
	Combined	72	76	67	71	61	72	67	56	77	61
AVERAGE pH	Upper	6.8	7.1	6.9	7.1	6.9	7.1	7.0	6.9	7.2	7.0
	Combined	8.4	8.3	8.5	7.8	8.5	7.9	8.6	7.1	8.6	7.3
AVERAGE DISSOLVED SOLIDS milligram/liter	Upper	1050	1150	800	800	900	950	1400	950	1600	830
	Combined	2250	2500	2600	--	18,000	1950	2900	1300	3780	1800

*Representative value

**E logs

(R.B.O.S.C., Oct. 1974/Feb. 1975)

Table 10

	CORE HOLE	AH-4	TO-1	TO-2	TO-3	GS-1	GS-2-3	GS-4-5	GS-6	GS-7	GS-8	GS-9	GS-10	GS-11
Upper	AQUIFER INTERVAL feet	720-950	See 705a	See 701	See 702	260-450	190-470	220-650	180-630	200-400*	490-720	410-610	640-820	670-910
Lower		1400-1920				900-1230	920-1200	1050-1400	1300-1780	1000-1200	1060-1460	1070-1240	1380-1600	1350-1429
Upper	STATIC WATER LEVEL feet	443	29	140	50.5	245	117	75	10	(10)	(340)	333	340	478
[illegible]		466				270	180	65	50	250	520	370	350	580
Lower		489	101	322	--	580	208	65	51	--	623	487	360	691
Upper	PRODUCTION RATE gpm (maximum)	130				100	200	560	375	80	70	140	280	125
Combined		265				160	500	865	575	250	250	300	455	310
Upper	APPARENT SPECIFIC CAPACITY gpm/ft.	--				.43	1.7	3.6	.50	.46	--	.5	1.6	3.7
Combined		--				.18	.05	6.4	.24	1.1	.84	.63	.24	1.2
Upper	APPARENT TRANSMISSIVITY gpd/ft.	250				--	2800	7930	14,700	770	--	--	2960	1200
Combined		--				300	1800	10,500	420	2400	1050	1220	570	1640
Upper	AVERAGE SPECIFIC CONDUCTANCE micromhos/cm	1400				1000	1160	1830	1200	1000	1100	1520	1160	980
Combined		3900				2055	2760	2850	2840	1500	2250	2800	4500	3700
Upper	AVERAGE TEMPERATURE °F	60				57	59	60	59	57	59	58	61	58
Combined		80				59	71	76	75	62	64	69	79	71
Upper	AVERAGE pH	7.9				6.7	7.0	6.7	7.6	7.0	7.0	6.7	7.1	7.0
Combined		8.5				6.8	7.4	7.5	7.9	7.0	7.5	7.4	8.1	8.1
Upper	AVERAGE DISSOLVED SOLIDS milligram/liter	1000				1350	1000	1000	940	800	720	1300	1250	1700
Combined		2720				3440	2300	1900	3600	1280	1400	2100	1900	2940

*Representative value [illegible]

[illegible]

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Table 10

AQUIFER CHARACTERISTICS FROM DRILLING

	CORE HOLE*	GS-13	GS-14	GS-15	GS-H1	GS-H2	GS-H3	GS-H4	GS-D16	GS-D17	GS-D18	GS-D19
Upper	AQUIFER INTERVAL feet	510-840	680-780	600-700	600-800	360-1160	100-1000	840-960	580-620	220-310	350-440	220-440
Lower		1280-1330	1200-1400*	1300-1400	1360-1500	1980-2030	1450-1650	1720-1990	128-1430	940-1020	1375-1540	820-1100
Upper	STATIC WATER LEVEL feet	387	(333)	279	643(50)**	241	22	487	--	--	--	--
Composite		519	410	320	700	320	93	540	--	--	--	--
Lower		543		334	798	348	128	535	--	--	--	--
Upper	PRODUCTION RATE gpm (maximum)	120	40	100	30	440	1020	200	190	120	1060	360
Combined		375	390	500	150	510	[illegible]	260	230	85	415	650
Upper	APPARENT SPECIFIC CAPACITY gpm/ft.	2.8	.43	2.8	.3	2.2	8.2	.9	--	--	--	--
Combined		*2.3	3.3	.66	.4	--	3.3	--	--	--	--	--
Upper	APPARENT TRANSMISSIVITY T, gpd/ft.	4600	1700	7500	519	2600	12,000	1200	--	--	--	--
Combined		3300	5000	600	410	--	8800	--	--	--	--	--
Upper	AVERAGE SPECIFIC CONDUCTANCE umhos/cm	1100	1100	1100	1200	1000	1040	1500	1200	1200	2200	950
Combined		2800	2950	3400	3400	8200	16,500	3840	4200	1500	4800	1750
Upper	AVERAGE TEMPERATURE °F	55	58	59	54	61	54	61	56	56	58	53
Combined		73	72	76	67	71	61	72	67	56	77	61
Upper	AVERAGE pH	7.0	6.8	7.1	6.9	7.1	6.9	7.1	7.0	6.9	7.2	7.0
Combined		7.6	8.4	8.3	8.5	7.8	8.5	7.9	8.6	7.1	8.6	7.3
Upper	AVERAGE DISSOLVED SOLIDS milligram/liter	1370	1050	1150	800	800	900	950	1400	950	1600	830
Combined		2320	2250	2500	2600	--	18,000	1950	2900	1390	3780	1900

*Representative value
**E logs

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Table 10

UPPER AQUIFER WATER LEVEL. OCTOBER 1975 - AUGUST 1976. (Below Ground Surface (ft))

	9 Oct.	20 Nov.	12 Dec.	28 Jan.	17 Feb.	29 Mar.	14 April	21 May	23 June	30 July	28 Aug.
AM 2A	389.45	387.63	386.41	385.17	384.34	383.19	382.50	381.85	--	379.40	379.09
AM 3	33.57	33.45	33.11	33.23	33.04	32.79	31.60	30.04	28.72	29.17	30.06
CE 702	52.40	52.30	52.39	52.64	52.65	52.80	52.66	53.02	54.50	53.38	53.70
CE 707	259.79	258.76	258.11	257.25	256.64	242.22	250.32	250.60	250.97	252.03	252.00
CE 708	48.87	50.60	49.86	51.78	51.80	51.30	47.72	44.81	46.43	44.30	46.91
CE 709	39.84	37.02	36.14	35.90	35.69	35.50	34.88	35.00	34.48	33.90	38.84
G-S 1	244.68	245.27	245.59	246.19	246.53	246.20	244.53	243.26	242.57	241.92	242.10
G-S 2-3	103.49	102.75	102.35	102.25	101.97	100.87	100.28	99.86	99.26	99.06	99.26
G-S 4-5	75.05	74.77	74.29	74.36	74.01	73.48	72.98	72.86	73.33	72.42	72.47
G-S 6	55.62	55.54	55.42	55.50	55.45	55.27	54.95	55.22	55.10	55.20	55.61
G-S 9	311.43	312.69	316.33	319.29	319.95	321.42	320.94	317.03	316.45	317.23	319.63
G-S 10	340.35	340.11	--	339.75	339.60	339.36	339.14	339.48	339.50	339.37	339.62
G-S 11	460.35	459.67	459.00	458.76	458.40	457.72	456.95	456.42	455.46	454.99	455.35
G-S 12	388.30	387.60	386.97	386.55	386.24	385.41	384.67	382.79	382.83	381.86	382.91
G-S 13	382.62	382.19	381.68	381.72	381.45	381.04	380.97	380.41	380.11	380.12	378.47
G-S 15	274.73			273.56	273.41	272.99	272.83	272.69	274.76	272.58	272.49
G-S M-1	620.64	621.13	--	619.10	618.77	618.71	625.57	619.31	619.40	619.95	620.26
G-S M-2	231.22	230.68	229.75	228.94	228.23	225.76	225.39	225.36	224.01	221.28	223.13
G-S M-3	21.59	21.96	20.32	19.16	19.21	18.57	17.50	17.72	18.75	18.58	18.46
G-S M-4	491.80	491.95	491.56	492.04	492.08	492.25	--	492.77	492.94	493.26	491.60
G-S M-5	235.73	235.81	235.24	235.70	235.64	235.51	235.38	235.75	235.80	235.94	235.90
TO-1	21.80	20.65	20.41	20.95	20.83	20.53	20.13	22.35	22.46	22.30	22.73
TO-2	113.36	113.36	112.96	112.93	112.73	112.57	112.18	113.81	113.70	111.32	111.44

-- Water levels not collected due to poor weather conditions making access to hole difficult or because problems with monitoring hole and equipment.

(R.B.O.S.C., Oct. 1977)

Table 11

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UPPER AQUIFER WATER LEVEL. OCTOBER 1976 - SEPTEMBER 1977. (Below Ground Surface (ft))

	21 Oct.	14 Nov.	Dec.	Jan.	Feb.	Mar.	19 April	9 May	June	July	Aug.	Sept.
AM 2A	378.27	378.20					376.91					
AM 3	33.15	34.81					35.10					
CE 702	54.19	54.34						56.68				
CE 707	251.90	251.68					253.56					
CE 708	48.59	49.39					52.38					
CE 709	33.88	33.71					35.35					
G-S 1	243.26	243.92					247.17					
G-S 2-3	98.23	98.06					96.66					
G-S 4-5	72.39	73.59					72.10	74.59				
G-S 6	56.02	54.14					57.12					
G-S 9	318.49	319.64					325.11					
G-S 10	339.53	339.40					339.87					
G-S 11	455.91	457.02					456.68					
G-S 12	383.58	384.79					384.29					
G-S 13	386.06	384.15					383.35					
G-S 15	272.26	272.20					272.40					
G-S M-1	620.96	622.15					623.99					
G-S M-2	222.65	221.98					220.74					
G-S M-3	17.96	17.85					16.45					
G-S M-4	493.62	493.84					495.11					
TO-1	23.54	23.64					23.96					
TO-2	110.85	111.42					110.93					

(R,B.O.S,C., Oct. 1977)

Table 12

TRANSMISSIVITY & COEFFICIENT OF STORAGE

FROM UPPER AQUIFER DRAWDOWN TEST

Observation Hole	CE-705A 264 gpm		CE-705A 259 gpm		GS-4-5 81.1 gpm		GS-12 64.1 gpm		TO-3 75.7 gpm	
	T	S	T	S	T	S	T	S	T	S
AM-2A							3831	2.34E-4		
AM-3							2628	8.31E-5		
CE-702									10748	5.94E-6
CE-705A	513	--	4864	--						
	4424	--	17313	--						
	19879	--								
CE-709	22827	4.50E-5	24770	6.20E-5						
GS-2-3									1702	9.57E-5
GS-4-5					5114	--				
					3580	--				
GS-6									22858	1.97E-4
GS-11							1989	1.94E-6		
							1156	2.97E-6		
							1614	1.23E-6		
GS-12							1453	--		
GS-M2			63512	7.27E-5						
TO-1	3435	9.70E-4	4188	7.95E-4						
	4955	3.00E-4	8212	9.74E-6						
	10594	2.84E-7	11797	7.15E-8						
TO-3									108	--
									604	--

FROM UPPER AQUIFER RECOVERY TEST

Observation Hole	CE-705A 264 gpm		CE-705A 259 gpm		GS-4-5 81.1 gpm		GS-12 64.1 gpm		TO-3 75.7 gpm	
	T	S	T	S	T	S	T	S	T	S
CE-702									2165	2.97E-3
									5972	2.72E-4
									17897	1.14E-9
CE-705A	6043	--	6415	--						
	12125	--	11955	--						
			30041	--						
CE-709	27829	6.61E-5	30417	5.49E-5						
GS-4-5					5176	--				
					2919	--				
GS-6									23913	3.84E-4
GS-11							6542	2.72E-6		
							1431	2.74E-6		
GS-12							8596	--		
							1568	--		
GS-M2			15242	2.95E-5						
TO-1	4421	9.12E-4	5865	2.96E-4						
	6093	1.54E-4	14432	4.27E-9						
	11015	2.68E-7	23965	5.65E-15						
TO-3									100	--

(R.B.O.S.C., Jul. 1975)

Table 13

LOWER AQUIFER WATER LEVEL. OCTOBER 1975 - AUGUST 1976. (Below Ground Surface (ft))

	9 Oct.	20 Nov.	12 Dec.	28 Jan.	17 Feb.	29 Mar.	14 April	21 May	23 June	30 July	28 Aug.
AM 2A	636.67	637.70	638.02	639.71	640.11	641.15	641.63	643.56	--	645.47	645.51
AM 3	310.40	311.27	311.56	313.34	313.73	314.65	315.31	316.90	317.67	318.80	319.50
CE 702	40.48	41.21	41.25	43.00	43.41	44.21	44.64	45.81	48.50	47.30	47.97
CE 707	567.51	568.70	569.21	570.67	571.04	572.19	572.53	--	573.00	573.81	574.78
CE 708	297.88	298.97	299.27	300.84	301.22	302.97	303.06	303.83	304.59	306.74	307.52
CE 709	154.31	155.55	154.92	157.62	158.63	158.87	159.60	160.82	160.61	162.63	163.23
G-S 1	602.65	602.43	602.13	602.13	601.70	601.64	601.58	601.91	601.76	601.67	602.36
G-S 2-3	254.92	255.98	256.61	258.03	258.32	259.43	259.81	261.05	261.79	262.79	263.66
G-S 4-5	98.31	99.55	100.09	100.57	101.95	102.89	103.40	104.46	105.12	--	105.74
G-S 6	44.06	45.88	46.26	47.72	48.12	49.01	49.45	50.65	51.29	52.41	52.89
G-S 9	513.25	514.31	514.68	516.10	516.22	517.19	517.96	517.56	518.14	518.51	519.65
G-S 10	389.69	390.81	--	392.76	393.06	394.01	394.57	396.13	396.89	398.04	398.71
G-S 11	721.76	723.02	723.36	725.51	725.53	726.65	727.18	727.63	728.46	729.60	730.46
G-S 12	649.79	649.76	650.08	651.97	652.30	653.36	653.92	655.54	656.45	659.06	656.86
G-S 13	573.82	574.98	575.36	577.08	577.34	578.39	578.96	580.40	581.58	582.80	579.40
G-S 15	363.99	365.27	365.64	367.28	367.64	368.71	369.24	370.79	371.79	372.69	373.41
G-S M-1	822.20	824.61	--	824.87	825.18	825.84	826.59	829.59	830.34	831.35	831.79
G-S M-2	354.96	355.03	354.44	355.14	354.69	354.60	354.73	353.64	355.46	355.31	355.76
G-S M-3	139.89	140.67	139.25	140.34	139.69	139.64	145.02	140.27	140.18	140.67	140.97
G-S M-4	562.50	563.58	563.95	565.32	565.65	566.55	--	--	--	571.65	568.23
TO-1	127.21	128.40	128.77	130.41	130.81	131.78	132.31	133.54	134.56	135.78	136.28
TO-2	356.68	357.83	358.31	359.62	359.95	361.01	360.93	362.93	363.57	364.64	365.30

-- water levels not collected due to poor weather conditions making access to hole difficult or because problems with monitoring hole and equipment.

(R.B.O.S.C., Mar. 1976/May 1976)

Table 14

LOWER AQUIFER WATER LEVEL. OCTOBER 1976 - SEPTEMBER 1977. (Below Ground Surface (ft))

	21 Oct.	14 Nov.	Dec.	Jan.	Feb.	Mar.	19 April	9 May	June	July	Aug.	Sept.
AH 2A	647.15	647.49					650.28					
AH 3	320.55	318.82					323.76					
CE 702	48.98	49.18						51.03				
CE 707	575.77	576.22					578.91					
CE 708	308.55	309.09					310.46					
CE 709	164.26	164.67					167.45					
G-S 1	601.94	602.02					602.94					
G-S 2-3	264.46	264.89					267.61					
G-S 4-5	107.84	105.19					111.02	110.72				
G-S 6	53.81	56.19					56.76					
G-S 9	520.87	521.17					523.75					
G-S 10	399.71	396.97					402.02					
G-S 11	731.42	731.96					734.71					
G-S 12	659.25	659.62					661.10					
G-S 13	584.46	584.91					587.62					
G-S 15	374.34	374.81					377.48					
G-S M-1	832.65	834.60					835.65					
G-S M-2	355.52	353.85					355.93	358.25				
G-S M-3	141.45	143.07					145.34					
G-S M-4	568.79	569.50					571.81					
TO-1	137.28	137.61					142.43					
TO-2	366.39	366.86					369.66					

(R.B.O.S.C., Jul. 1975)

Table 15

TRANSMISSIVITY & COEFFICIENT OF STORAGE
FROM
LOWER AQUIFER DRAWDOWN TEST

Observation Hole	GS-016 174 gpm		GS-017 275 gpm		GS-017 275 gpm		GS-019 667 gpm		GS-019 667 gpm	
	T	S	T	S	T	S	T	S	T	S
AM-2A	21605 5774	2.68E-4 3.99E-4			8492	4.91E-5	19420 10943 5766	7.08E-5 1.13E-4 1.48E-4	17301	8.03E-5
AM-3	14192 6122	2.62E-4 4.06E-4			27533 7615	5.68E-5 7.20E-5	20522 11499 5952	1.08E-4 1.51E-4 1.88E-4	20689	1.23E-4
CE-702	24382 7901	4.12E-5 4.22E-5	17835	7.68E-5	44041 12951	4.48E-5 4.22E-5	22204 12683 7755	4.66E-5 8.77E-5 1.40E-4		
CE-707	11861 6635	1.92E-5 3.38E-5			10687 7205	6.09E-5 8.98E-5	14292 6936	5.04E-5 1.11E-4	12296	5.91E-5
CE-708	13522 6432	3.17E-5 6.04E-5			12839 7917	5.63E-5 6.92E-5	14533 10228 5547	8.66E-5 1.42E-4 2.05E-4	13993	1.00E-4
CE-709	7630	6.99E-5	9176	1.73E-4	19890 8967 6339	4.68E-5 5.75E-5 8.53E-5	14754 9474 5879	9.97E-5 1.76E-4 3.13E-4	11637	1.02E-4
GS-1	12871 6740	2.26E-5 3.53E-5	10014	5.23E-5	8712	8.33E-5	18633 11901	6.01E-5 7.93E-5	18524	5.89E-5
GS-2-3	12747 6674	3.82E-5 4.51E-5	11556	3.99E-5	7534	1.01E-4	12259 6303	5.14E-5 1.07E-4	10827	5.34E-5
GS-4-5	17487 6742	3.96E-5 4.70E-5	11757	3.08E-5	17322 10555 6972	4.40E-5 4.42E-5 6.13E-5	16221	5.10E-5		
GS-6	16546 7002	5.71E-5 5.36E-5	19379	1.89E-5	15031 8094	3.21E-5 4.32E-5	20694 10457 6340	5.34E-5 1.19E-5 1.95E-4	13377	5.78E-5
GS-8	19394 6327	2.08E-4 2.38E-4			8543 5479	4.61E-5 5.95E-5	12064 5890	5.26E-5 1.27E-4	11748	6.03E-5
GS-9	6277	6.83E-5			9505 5915	6.14E-5 8.62E-5	17266 12937 5426	1.65E-4 2.47E-4 5.79E-4	13223	2.13E-4
GS-10	20921 6642	5.29E-5 7.69E-5			11354	2.57E-5	19622 12122 6523	7.87E-5 1.65E-4 3.32E-4	14995	9.89E-5
GS-11	14031 5775	3.87E-5 1.16E-4			7956	3.49E-5	17265 11678 4107	4.78E-5 1.04E-4 9.23E-5	17412	5.46E-5
GS-12	8046 21071 5712	2.81E-4 5.14E-4 1.24E-4			15123 4790	5.07E-5 4.85E-5			14719	7.37E-5
GS-13	17415 5915	7.58E-5 4.52E-4			13565 4798	5.88E-5 5.97E-5	17870 9024 5494	2.80E-4 4.52E-4 4.97E-4	15070	9.67E-5
GS-15	20057 6225	7.64E-5 8.59E-5			12079	2.57E-5	19629 10289 6052	5.64E-5 9.07E-5 1.16E-4	17111	6.60E-5
GS-M1	7800	3.68E-5			6408	4.33E-5	13233 10005 6286	3.89E-5 4.72E-5 6.45E-5	19483	5.19E-5
GS-M4	8304	2.93E-5			7137	1.10E-4	15172 8293	7.44E-5 7.82E-5		
GS-016							14260	1.42E-4		
GS-017	16375 7040	4.9E-5 4.7E-5					12176 9321 6553	3.76E-5 4.82E-5 6.82E-5	13023	5.12E-5
TO-1	10477 1184	1.13E-4 1.04E-4			11336 6520	3.64E-5 5.36E-5	5300 9235 5233	3.77E-2 1.10E-2 6.58E-2	14576 10171	1.66E-3 5.63E-3
TO-2	24045 7220	3.95E-5 4.37E-5	5907	3.71E-4	5657 8955 4220	5.84E-4 1.20E-5 4.04E-3	17077 10773 6700	3.93E-5 4.99E-5 7.53E-5	11759	4.76E-5

(R.B.O.S.C., Jul, 1975)

Table 16

TRANSMISSIVITY & COEFFICIENT OF STORAGE
FROM
LOWER AQUIFER RECOVERY TEST

Observation Hole	GS-D16 174 gpm		GS-D17 275 gpm		GS-D17 275 gpm		GS-D19 667 gpm		GS-D19 667 gpm	
	T	S	T	S	T	S	T	S	T	S
AM-2A					46931	1.42E-4	32694	4.01E-5	29344	1.44E-4
AM-3							34389	6.08E-5	48274 30568	2.20E-4 2.50E-4
CE-702					61477	5.16E-5	2902 6723 14693	4.09E-5 3.28E-6 3.79E-10	30114	7.25E-5
CE-707	48873	8.45E-6	13502	9.90E-5	11260	5.73E-5	15784	3.50E-5	17372	8.16E-5
CE-708	36173	4.90E-6	27784	5.78E-4	21084	5.64E-5	18024	4.29E-5	20170	1.38E-4
CE-709	68840	3.79E-5	28052	1.51E-4	17931	5.66E-5	16920	7.15E-5	18226	1.06E-4
GS-1			14827	1.43E-4	10205 33509	8.71E-5 3.57E-7	26885	4.92E-5	25874	1.13E-4
GS-2-3	88655	2.63E-6	10379 25921	2.23E-4 3.29E-5	11338	8.96E-5	15528	5.03E-5	17943	6.53E-5
GS-4-5	135333	1.25E-5	51931	1.08E-2	25961	6.59E-5				
GS-6					29735	9.29E-5	20338	1.16E-4	26220	8.59E-5
GS-8	50932	2.66E-5			14349	4.86E-5	17193	2.53E-5	16594	7.19E-5
GS-9	32329	1.21E-5			14078	6.05E-5	18291	6.93E-5	18922	7.95E-4
GS-10					14844	6.59E-5	22261	6.78E-5	25531	1.02E-4
GS-11	20082	6.05E-6			20344	9.81E-5	33516	2.93E-5	25284	1.04E-4
GS-12	6622 19967 32751	1.81E-4 1.20E-4 7.16E-7	6363	2.30E-5	48819	2.95E-5	28187	3.33E-5	24494	9.70E-5
GS-13			6516	3.04E-5	35204	2.61E-5	25396	3.30E-5	21547	1.10E-4
GS-15							35075	4.36E-5	73282 28166	1.32E-4 1.28E-4
GS-M1					6939	4.71E-5	24120	3.70E-5	18264	7.76E-5
GS-M4							33820	1.35E-4	36986	3.49E-4
GS-D17	63363	4.95E-5	6854				15603	3.72E-5	16162	8.01E-5
GS-D19									20170	1.38E-4
TO-1					21722	6.39E-5	14942	5.82E-5	14780 17743	1.89E-3 6.68E-4
TO-2	61872	4.93E-5	8498	7.44E-5	7205	1.65E-4	16042	4.12E-5	16894	7.22E-5

(R.B.O.S.C., Jul. 1975)

Table 17

VARIABLE DIMENSIONS FOR WELL DETAIL
TYPICAL NEW REINJECTION HOLE

Hole No.	Depth to Upper Aquifer A (Top)	Depth to Upper Aquifer B (Bottom)
NR-1	220	540
NR-2	200	500
NR-3	300	500
NR-4	400	600
NR-5	400	700

(R.B.O.S.C., Sept. 1977)

Table 18

DRILL HOLE FUTURE USE SUMMARY

Hole	Future Use	Hole	Future Use
ON-TRACT HOLES			
G-S 1	NU	CE-701	NU
G-S 2-3	RI	CE-702	MH
G-S 4-5	RI	CE-703	P&A
G-S 6	RI	CE-705A	TRI
G-S 7	P&A	CE-707	RI
G-S 8	NU	CE-708	RI
G-S 9	NU	CE-709	NU
G-S 10	MH		
G-S 11	MH	TO 1	NU
G-S 12	NU	TO 2	RI
G-S 13	NU	TO 3	NU
G-S 14	P&A		
G-S 15	MH	G-S D16	NU
		G-S D17	NU
AM 2A	MH	G-S D18	NU
AM 3	RI	G-S D19	NU
AM 4	P&A		
OFF-TRACT HOLES		PROPOSED HOLES ON-TRACT	
G-S M1	MH	NM 1	MH
G-S M2	NU	NR 1	RI
G-S M3	NU	NR 2	RI
G-S M4	MH	NR 3	RI
G-S M5	NU	NR 4	RI
		NR 5	RI
		D 1-12	D

TOTALS

RI	(Reinjection)	= 12
TRI	(Temporary Reinjection)	= 1
MH	(Monitoring Hole)	= 8
D	(Dewatering Hole)	= 12
NU	(Not Used)	= 16
P&A	(Plugged and Abandoned)	= 4
		53

(R.B.O.S.C., Sept. 1977)

Table 19

STRIBUTION (daily)
A RML JFM
Y EAZ
M ~~DDP~~ MBT

(full sheets)
JJS PWM CLS HWE
FVW KLB RLH DJM
Hodgson ~~Wright Water~~
AOSO

NOTE
Form revised 3-10-80. Flows are calculated using accumulator totals on wel flow meters. The 24 hour change in gallons flow is divided by the 1440 min in a day to obtain gpm. Reading are taken at 12:00 noon on the day prior t

	DEWATERING													REINJECTION							
981	Well Depths						D-5		D-6		D-8		Mine	GS-4-5		GS-6		TO-3		Fire	Out System Into Sys.
te	D-1	D-5	D-6	D-7	D-8	D-9	Pres/Flow		Pres/Flow		Pres/Flow		Inflow	Pres/Flow		Pres/Flow		Pres/Flow		Tank	+ or -
-16		554	466		387				187	215	156	298	1218	90	235	56	249	91	166	235	1731 1897 -166
-17		554	464		391				188	215	156	298	1263	88	227	66	319	89	161	317	1776 2029 -253
-18		554	469		391				187	215	156	298	1185	87	224	66	331	88	160	364	1698 2090 -392
-19		554	469		391				186	214	156	297	1181	86	229	66	330	87	164	477	1692 2206 -514
-20		554	466		394				186	217	156	298	1205	89	235	40	303	91	166	477	1720 2190 -470
-21		554	469		396				186	215	155	299	1202	89	263	40	151	90	183	422	1716 2046 -330

Table 20

DAILY TRACT C-a REPORT

sneets)
PWM CLS IME
KLB RLH DJM
on ~~Wright Water~~
AOSO

NOTE
Form revised 3-10-80. Flows are calculated using accumulator totals on well. flow meters. The 24 hour change in gallons flow is divided by the 1440 minutes in a day to obtain gpm. Reading are taken at 12:00 noon on the day prior to report.

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DEWATERING					REINJECTION						
D-9	D-5 Pres/Flow	D-6 Pres/Flow	D-8 Pres/Flow	Mine Inflow	GS-4-5 Pres/Flow	GS-6 Pres/Flow	TO-3 Pres/Flow	Fire Tank	Out System Into Sys. + or -	Ret. 5 MOD 2 Corehole	Additional Commen
		187 215	156 298	1218	90 235	56 249	91 166	235	1731 1897 -166	597	TO-2 (P-8/f1-210) GS-20 (P-1/f1-705) GS-21 (P-17/f1-95) Water Trucks - 0 Potable Water - 2
		188 215	156 298	1263	88 227	66 319	89 161	317	1776 2029 -253	597	TO-2 (P-8/f1-210) GS-20 (P-1/f1-699) GS-21 (P-16/f1-94) Water Trucks - 0 Potable Water - 2
		187 215	156 298	1185	87 224	66 331	88 160	364	1698 2090 -392	597	TO-2 (P-8/f1-209) GS-20 (P-1/f1-696) GS-21 (P-16/f1-96) Water Trucks - 5 Potable Water - 5
		186 214	156 297	1181	86 229	66 330	87 164	477	1692 2206 -514	597	TO-2 (P-8/f1-210) GS-20 (P-1/f1-694) GS-21 (P-15/f1-98) Water Trucks - 0 Potable Water - 4
		186 217	156 298	1205	89 235	40 303	91 166	477	1720 2190 -470	597	TO-2 (P-8/f1-209) GS-20 (P-1/f1-698) GS-21 (P-18/f1-98) Water Trucks - 0 Potable Water - 4
		186 215	155 299	1202	89 263	40 151	90 183	422	1716 2046 -330	597	TO-2 (P-8/f1-210) GS-20 (P-0/f1-711) GS-21 (P-17/f1-102) Water Trucks - 0 Potable Water - 4

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Table 20 (Cont.)

___ Semiannually (S)

HYDROLOGY MONITORING PROGRAM CHECKLIST

Operational Field Monitoring

Locations	pH	Flow	TSS	Cond. or TDS	Temp. (°F)+	Oil Grease	Water Level	Lab Sample Reqd.*	Comments
Discharge	D	D	D	D	NA	D	NA	D-W	TSS and TDS sent to Lab daily.
Corral Gulch									
Injection Water	D-M	D	D	D	D	NA	NA	D-M-S	TSS and TDS sent to Lab daily.
Composite									
Upper Aquifer Holes	M	NA	NA	M	M	NA	D	M-S	
AM 2A									
CE 701									
CE 702									
CE 707									
CE 708**									
CE 709									
G-S 2-3**									
G-S 9									
G-S 10									
G-S 11									On hold for testin
TO 1 (CE 705A)									
GS 1**									

*Check attached listings for required laboratory analysis

**Weekly water levels only except during startup for pump tests; then daily water levels are required 3 days prior and 3 days after startup.

Table 21

Operational Field Monitoring

Checklist (continued)

Locations	pH	Flow	TSS	Cond. or TDS	Temp. (°F)+	Oil Grease	Water Level	Lab Sample Reqd.*	Comments
Lower Aquifer Holes	NA	NA	NA	NA	NA	NA	D	NA	
CE 702									
CE 709									
G-S D-17									
G-S 4-5									
TO 1									

Table 21 (Cont.)

Attachment 1 to

Operational Field Monitoring Checklist

Listing of Required Laboratory Analyses and Appropriate Procedures

Weekly Samples:

Sample locations - all surface discharge points

Number of samples to be collected - ____________________

Quantity required - __________________

Parameters	Methodology	Sample Preservation	Type Container
Fluoride			
Boron			
_______			

Monthly Samples:

Sample locations - upper aquifer holes and reinjection water

Number of samples to be collected - ____________________

Quantity required - ____________________

Parameters	Methodology	Sample Preservation	Type Container
Alkalinity			
Calcium			
Chloride			
Fluoride			
Magnesium			
Silica			
Sulfate			
Sodium			

(continued......)

Table 22

Sample locations - upper aquifer holes
Number of samples to be collected - ________________
Quantity required - ________________

Parameters		Sample Preservation	
Alkalinity			
Aluminum (Al)			
Ammonia (NH_3)			
Arsenic (As)			
Barium(Ba)			
Beryllium (Be)			
Bismuth (Bi)			
Bromide (Br)			
Boron (B)			
Dissolved Org. Carbon (C)			
Cadmium (Cd)			
Chromium (Cr)			
Copper (Cu)			
Cyanide (Cn)			
COD			
Dissolved Solids (DS)			
Germanium (Ge)			
Gallium (Ga)			
Iron (Fe)			
Lead (Pb)			
Lithium (Li)			
Manganese (Mn)			
Mercury (Hg)			
Molybdenum (Mo)			
Nickel (Ni)			
Nitrate plus Nitrite			
Phenols			
Diss. Phosphate			
Selenium (Se)			
Silver (Ag)			
Strontium (Sr)			
Sulfide (S^{-2})			
Titanium (Ti)			
Vanadium (V)			
Zirconoum (Zr)			
Zinc (Zn)			
Color			
Odor			
Gross Alpha			
Ra^{226}			
Natural Uranium (U)			
Gross Beta			
Sr^{90}			
Ce^{137}			

Table 22 (Cont.)

Sample (V) — Periodically (P)
— Annually (A)
— Bimonthly (BM)

(Rev.0, 12-6-

Hydrology Monitoring Program Checklist

Environmental Field Monitoring

Locations	pH	Flow	Sediment	Cond.	Temp.(°C)	Water Level	Lab Sample Reqd.*	Comments
Stream Gages	M-Q	C	P (B&D only)	C	C	NA	M-Q-S	
A								
B								
C								
D								
E								
F								
84 Ranch**								Bimonthly onl
TIS** Upper Yellow								Bimonthly onl
TIN** Lower Yellow								Bimonthly onl

Locations	pH	Flow	Cond.	Temp.(°C)	DOC	Water Level	Lab Sample Reqd.*	Comments
Springs & Seeps	Q	Q	Q	Q	Q	NA	NA	
1								
2								
3								
5								
8								
14								
Impoundments	Q	NA	Q	Q	Q	NA	S	When water pre

* See attached list for required laboratory analysis
** pH, flow, and conductivity daily only at startup of discharges, twice monthly thereafter

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Table 23

(continued)

Locations	pH	Flow	Sediment	Cond.	Temp.(°C)	Water Level	Lab Sample Reqd.*	Comments
Alluvial Aquifer Holes	M,S,Q	NA	NA	M,Q	M,Q	C,Q	M,Q,S	
G-S S-6								
G-S S-7								
G-S S-8								
G-S S-13								
G-S S-14								
G-S S-25								Bimonthly
G-S S-26								Bimonthly
G-S S-27								Bimonthly
G-S S-28**								Bimonthly
G-S S-28A**								Bimonthly o
G-S S-29**								Bimonthly o
G-S S-29A**								Bimonthly o

Deep Aquifers	M,S	NA	NA	M	M	C	M,S	
AM 3 (u) ***								
G-S M1 (u)								
G-S M2 (u)***								
G-S M3 (u)***								
G-S M4 (u)								
G-S 15(u&l)								

* See attached list for required laboratory analysis

** To be dropped from program upon AOSO approval

*** To be brought on line as soon as recording equipment becomes available

Table 23 (Cont.)

Water Quality Laboratory Parameters and Frequency of Sampling

Monthly Samples:

Sample locations - stream gaging stations (USGS), alluvial aquifers, deep aquifers

Number of samples collected - ____________

Quantity required - ____________ Special handling required ________________

Parameters - Alkalinity, Ca, Cl, F, Mg, Si, SO_4, Na

Quarterly Samples:

Sample locations - Stream gaging stations, impoundments, alluvial aquifers

Number of samples collected - ____________

Quantity required - ____________ Special handling required ________________

Parameters - Alkalinity, F, Ca, Mg, SO_4, Cl, K, HCO_3, NO_2+NO_3, Na, Si, DOC (excep alluvial holes)

Semiannual Samples (surface water):

Sample locations - Stream gaging stations, impoundments

Number of samples collected - ____________

Quantity required - ____________ Special handling required ________________

Parameters - Br, Alkalinity, BOD, DOC, B, Ca, Cond., F, Mg, K, Si, Na, COD, Fecal coliform, pesticides, total coliform, Mb, Sr, CN, MBAS, oil and greas SO_4, Color, Odor, NH_3, Bicarbonate, Carbonate, Cl, TDS, KB.. NO_2+NO_3, Diss P, turbidity, DO, phenols, S^{-2}, radioactivity, Li, Mn, pH, Temp., Tot. P, Ortho P, SOC, Ba, Be, Ge, Gr, Ni, Ti, V, Zr, Al, As, Ca, Cr, Se, Hg, Zn, Cw, Fe, Pb

Semiannual Samples (alluvial water); Annual Samples (deep aquifers):

Sample locations - Alluvial holes (8), deep aquifers (6)

Number of samples collected - ____________

Quantity required - ____________ Special handling required ________________

Parameters - Se, Al, NH_3, As, Ba, Be, Bi, Bicar., Br, B, DOC, Ca, Carb., Cd, Cl, Cr, Cw, oil and grease, Alk., Si, TDS, Ge, Ga, F, Fe, Pb, Li, Mg, Mn, Hg, Mo, Ni, NO_2+NO_3, phenols, Diss. P, R, CN, COD, Na, Sr, SO_4, S^{-2}, Ti, V, Zr, Zn, Color, Odor, Radioactivity

Table 23 (Cont.)

Water Property or Chemical Constituent	Measurement Method	In Field	In Lab
Cr	Spectrographic		x
Co	Spectrographic		x
Ga	Spectrographic		x
Fe	Spectrographic		x
Li	Spectrographic		x
Mn	Spectrographic		x
Mo	Spectrographic		x
Ni	Spectrographic		x
Ra	Spectrographic		x
Sr	Spectrographic		x
Ti	Spectrographic		x
Th	Spectrographic		x
U	Spectrographic		x
V	Spectrographic		x
Y	Spectrographic		x
Zr	Spectrographic		x
Suspended Solids	Gravimetric		x
Turbidity	Turbidometric		x
Total hardness	Titrametric		x
CO_2	Titrametric		x
H_2S	Titrametric		x
Free chlorine	Field test kit	x	
P_2O_5	Colorametric		x
Ag	Spectrographic		x
Coliform (total & fecal)	Membrane filter		x
Be	Spectrographic		x
Asbestos	Microscopic		x

Water Property or Chemical Constituent	Measurement Method	In Field	In Lab
Temperature	Thermometer	x	
Specific Conductance	Conductivity meter	x	
COD	Titrametric		x
TDS	Evap. solids		x
pH	Instrumental		x
Dissolved oxygen	Field test kit	x	
Ca	Titrametric		x
Mg	Atomic absorption		x
Na	Atomic absorption		x
K	Atomic absorption		x
CO_3	Titrametric		x
HCO_3	Titrametric		x
Cl	Titrametric		x
SO_4	Gravimetric		x
S	Gravimetric		x
F	Colorametric		x
NH_3	Colorametric		x
NO_3	Colorametric		x
OH	Titrametric		x
SiO_2	Colorametric		x
Al_2O_3	Colorametric		x
Pb	Spectrographic		x
Cu	Spectrographic		x
Hg	Spectrographic		x
Se	Fluorometric		x
Al	Spectrographic		x
Zn	Spectrographic		x
B	Spectrographic		x
As	Colorametric		x
Ba	Spectrographic		x
Bi	Spectrographic		x
Cd	Spectrographic		x
Ce	Spectrographic		x

Table 23 (Cont.)

Summary Hydrology Monitoring Program

	Continuously	Quarterly	Semi-Annually
SURFACE WATER			
Stream Gaging Stations 1			
Sediment (periodically)	x (6)		
Conductivity	x (6)		
Temperature	x (6)		
Flow	x (6)		
Limited water quality		x (6)	
Baseline water quality			x (6)
Springs and Seeps 1			
Flow		x (6)	
Conductivity		x (6)	
Temperature		x (6)	
pH		x (6)	
GROUNDWATER			
Alluvial Holes 1			
Water Levels	x (3)	x (5)	
Limited water quality		x (8)	
Baseline water quality			x (8)
Dual Aquifer Monitor Holes			
Water levels	x (4)		
DEWATERING WELLS			
Flow	x (12)		
Sediment 2 (periodically)	x		
pH 2	x		
Temperature 2	x		
Conductivity 2	x		
Water level alarm	x (12)		
REINJECTION WELLS			
Water level alarm	x (12)		
Baseline water quality 2			x

( ) Indicates the number of samplings sites
1 When water is present.
2 Composite sample before reinjection

Note: Samples will be retained 30 days following submission of year end report.

(R.B.O.S.C., Sept. 1977)

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Table 24

DATA COLLECTION SCHEDULE FOR DEEP AQUIFER

Monthly

Water Levels Measure

Semi-Annually

Water Sample Analyzed For:

- Alkalinity
- Aluminium
- Ammonia
- Arsenic
- Ba
- Be
- Bi
- Bicarbonate
- Br
- B
- Dissolved Organic Carbon
- Calcium
- Carbonate
- Cd
- Chloride
- Cr
- Cu
- Cyanide
- COD
- Dissolved Solids
- Ge
- Ga
- Fluoride
- Iron
- Lead
- Li
- Mg
- Mn
- Hg
- Mo
- Ni
- Nitrate plus Nitrite
- Phenols
- Dissolved Phosphate
- Pottassium
- Se
- Silica
- Na
- Sr
- Sulfate
- Sulfide
- Ti
- V
- Zr
- Zn
- Color
- Odor
- pH
- Temperature
- Conductance

Radioactivity
- Gross Alph
  - 4 pci/l ^{226}Ra
- Gross Beta
  - 100 pci/l ^{90}Sr
  - ^{137}Ce

(R.B.O.S.C., Jun. 1976/Aug. 1976)

DEEP WELL MONITORING SUMMARY

	1977										1978										
Well #	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
AM 2A		X+						X+	X+			X+	X								
AM 3		X+						X+				X									
CE 702			X+					X+	X+	X+	X+	X+	X+	X+							
CE 707		X+						X+				X									
CE 708		X+						X+				X									
CE 709		X+						X+				X									
G-S M1		X+						X+	X+		X	X	X	X+	X	X+ B	X	X	X		X
G-S M2		X+	X+					X+	X+							B					
G-S M3		X+						X+	X+												
G-S M4		X+						X+	X+			X	X	X+	X	X+ B	X	X	X	X	X
G-S M5	X	C	X					X	X												
G-S 1		X+						X+				X									
G-S 2-3		X+						X+				X									
G-S 4-5	X+	X+	X+			X+		X+		X+		X									
G-S 6		X+						X+													
G-S 9		X+						X+	X+			X									
G-S 10		X+						X+	X+			X									
G-S 11		X+						X+	X+		X	X+	X	X+	X	X+ B	X	X			
G-S 12		X+						X+	X+			X									
G-S 13		X+						X+	X+			X									
G-S 15		X+						X+	X+		X	X	X+	X+	X+	X+ B	X+	X+	X+	X+	X+
TO-1		X+						X+				X									
TO-2		X+						X+				X+									

X+ = Both upper and lower water level measured
X = Upper aquifer water level measured
B = Baseline water quality
C = Water level, conductivity, temperature, pH

(R.B.O.S.C., Dec. 77/Nov. 78)

Table 25

HYDROLOGY MONITORING PROGRAM SUMMARY - MIS DEVELOPMENT AREA

Station Class.	Monitoring Effect & Station Identification	Sampling Program[1/]				
		D	W	M	Q	A
Type I Control	**Streams** B-USGS C-USGS	Continuous monitors, quarterly water quality				
	Springs and Seeps SPG-3 SPG-4 SPG-5 SPG-8 SPG-14 SPG-MILL				FWQ[2/] BWQ[4/]	TWQ[3/]
	Alluvial Aquifer GS-S7 CS-S8		WL[5/] FWQ		BWQ	TWQ
	Deep Aquifer GS-10U GS-15U GS-9U GS-15L CE-708U			WL		BWQ TWQ FWQ
	Erosion & Sedimentation YES-1A YES-3				Channel Cross-Section	
Type II Near Field	**Streams** D-USGS[6/] YCULDIS YSEOFL Y MET 3 YBOXFL	Continuous monitors, quarterly water quality, Plus: Flow FWQ		BWQ		TWQ
	Impoundments MIS East Retention Pond MIS West Retention Pond MIS East Runoff Pond MIS West Runoff Pond East Shaft Settling Pond Sour Water Ponds 1-7	WL Vol In&Out Flow FWQ			BWQ	TWQ
	YLEACH-1 YPZR 1-4	CK, FWQ if wet				
	Alluvial Aquifer GS-S25 GS-S26 GS-S27 GS-S27A	WL	FWQ	BWQ		TWQ
	Deep Aquifer CE-709U GS-MDP 2CU CE-702U CE-705AU		WL	FWQ	BWQ	TWQ
	Erosion & Sedimentation YES-4 YES-7 YES-5 YES-8 YES-6				Channel Cross-Section	

(R.B.O.S.C., Feb. 1981)

Table 26

(Continued)

Station Class.	Monitoring Effect & Station Identification		Sampling Program[1] D	W	M	Q	A
Type III Far Field	**Streams**						
	F-USGS		Continuous USGS gaging station				
	YUPRYEL				Flow	BWQ FWQ	TWQ
	Alluvial Aquifer						
	GS-S11 GS-S11A	GS-S24			WL FWQ	BWQ	TWQ
	Deep Aquifer					WL	TWQ
	GS-M2U GS-M3U	GS-M5U					FWQ BWQ
	Erosion & Sedimentation					Channel	
	YES-9 YES-10	YES-11				Cross-Section	

[1] D=Daily, W=Weekly, M=Monthly, Q=Quarterly, A=Annually

[2] FWQ=Field measurements including pH, temperature, conductivity

[3] TWQ=Trace water quality, see text

[4] BWQ=Basic water quality, see text

[5] WL=Water level

[6] Monthly water quality

(R.B.O.S.C., Feb. 1981)

Table 26 (Cont.)

HYDROLOGY MONITORING PROGRAM SUMMARY - DEWATERING/REINJECTION/DISCHARGE

Station Class.	Monitoring Effect & Station Identification	Sampling Program 1/ D	W	M	Q	A
Type I Control (Unaffected)	Springs & Seeps SPG-3 SPG-8 SPG 4 SPG-MILL SPG-5				Flow FWQ2/	
	Deep Aquifer GS-M9U AM-3U GS-MIOU GS-M11U GS-9U GS-M12U AM-2U CE-708U			WL3/		BWQ4/ TWQ5/
Type II Near Field (Potentially Affected)	Active Dewatering Wells GS-D6U GS-D8U	Flow WL Press FWQ	F,B6/		BWQ	TWQ
	Mine Seepage MISUMP	Flow	FWQ		BWQ	TWQ
	Active Reinjection Wells YCOINJ GS-6U TO-2U GS-20U GS-4-5U GS-21U TO-3U	Flow Press FWQ			BWQ	TWQ
	Discharge Sites/Streams YFLDIS	Flow FWQ	F,B			
	Deep Aquifer GS-D5U GS-D1U GS-D4U	WL				
	GS-MDP2CU CE-702U	WL		FWQ	BWQ	TWQ

(R.B.O.S.C., Feb. 1981)

Table 27

DRINKING WATER QUALITY STANDARDS
(Standard Wet Chemical Analysis)

Chemical Constituent	Limits (mg/l) or (ppm)			Comment
	Recommended¹	Maximum¹	Unestablished¹	
Alkalinity				Generally not harmful
Alkyl Benzene Sulfonate (ABS)[5]	0.5			Taste, Frothing
Arsenic[5]	0.01	0.05		Poisoning
Barium[5]		1.0		Poisoning
Bicarbonate			700	Taste
Cadmium[5]		0.01		Poisoning
Calcium			200	Hardness
Carbon Chloroform[5] Extract (CCE)	0.2			Indicator of Potentially Toxic Material
Carbonate			20	Taste
Chloride	250.0			Taste & Laxative Prop.
Chromium[5]		0.05		Poisoning
Copper[5]	1.0			Taste
Cyanide[5]	0.01	0.2		Poisoning
Fluoride	0.8-1.7	1.4-2.4		Mottling of Teeth
Hardness			500	Economics, Health
Iron	0.3			Staining, Taste
Lead[5]		0.05		Poisoning
Magnesium			125	Laxative
Manganese	0.05			Staining, Taste
Nitrate	45.0			Methemoglobinemia in Infants (Blue babies)
Phenol[5]	0.001			Taste
Selenium[5]		0.01		Poisoning
Silicon dioxide				Generally not harmful
Silver[5]		0.05		Poisoning—Discoloration of Membranes
Sodium			115	Heart Conditions
Sulfate	250.0			Laxative & Taste Prop.
Total Dissolved Solids (TDS)	500.0			Laxative, Taste
Zinc[5]	5.0			Taste
Radium-226[5]		3.0 pc/l		Poisoning
Strontium -90[5]		10.0 pc/l		Poisoning

Wright Water Engineers, Inc., Nov. 1972)

Table 28

DRINKING WATER QUALITY STANDARDS (Continued)
(Qualitative Spectrographic Analysis)

Chemical Constituent	Limits (mg/l) or (ppm) Recommended[1]	Maximum[1]	Unestablished[3]	Comment
Samarium				
Scandium				
Selenium[5]		0.01		Poisoning
Silicon				Generally not harmful
Silver		0.05		Skin pigmentation
Sodium	10[3]		115	Heart conditions
Strontium		10 pc/l		Poisoning
Tantalum				
Terbium				
Thallium[4]			.0002	Poisoning
Thorium			Unknown	Radioactive
Thulium				
Tin				Generally not harmful
Titanium				Generally not harmful
Tungsten				Usually not present
Uranium[4]			.001	Poisoning
Vanadium				Has beneficial effects
Ytterbium				
Yttrium			Unknown	Radioactive
Zinc	5.0			Taste, poisoning
Zirconium				Generally not harmful

1. Established by U. S. Public Health Service and adopted b Colorado Department of Health.
2. Established by Colorado Department of Health.
3. Reported in California State Water Resources Control Board'Water Quality Criteria" 1963.
4. Minimum detectable amount may not be low enough to detect recommended, maximum or unestablished limit.
5. Not analyzed.

Recommended limits should not be exceeded whenever more suitable water supplies are available at reasonable cost. Units expressed in milligrams per liter (mg/l) Note: 1.0 mg/l = 1.0 parts per million (ppm).

Maximum limits, if exceeded, are grounds for rejection of the water supply. Units expressed in mg/l and pico-Curies per liter (pc/l).

Unestablished limits are recommened by some members of the scientific community but not adopted by the controlling governmental agencies.

DRINKING WATER QUALITY STANDARDS
(Qualitative Spectrographic Analysis)

Chemical Constituent	Limits (mg/l) or (ppm) Recommended[1]	Maximum[1]	Unestablished[3]	Comment
Aluminum				Generally not harmful
Antimony			Unknown	Poisoning
Arsenic[4]	0.01	0.05		Poisoning
Barium		1.0		Poisoning
Beryllium				Generally not harmful
Bismuth				
Boron			30	Food preservative
Cadmium[4]		0.01		Poisoning
Calcium			200	Hardness
Cerium			Unknown	Radioactive
Cesium			Unknown	Radioactive
Chromium(+6)		0.05		Poisoning
Cobalt			Unknown	Radioactive
Columbium				
Copper	1.0			Taste, staining
Dysprosium				
Erbium				
Europium				
Gadolinium				
Gallium				
Germanium			<100	Poisoning
Gold				Usually not present
Hafnium				
Holmium				
Indium				
Iridium				
Iron	.3			Staining, taste
Lanthanum				Generally not harmful
Lead		0.05		Poisoning
Lithium			5.0	Not given
Lutetium				
Magnesium	125[2]			Taste, hardness
Manganese	0.05			Staining, taste
Mercury[4]			0.005	Poisoning
Molybdenum				Usually not present
Neodymium				
Nickel			1.0	Unknown
Osmium				
Palladium				Unknown
Platinum				
Potassium			2000	Laxative
Praseodymium				
Radium(226)[4]		3 pc/l		Poisoning
Rhenium				
Rhodium				
Rubidium				Generally not harmful
Ruthenium				Generally not harmful

(Wright Water Engineers, Inc., Dec. 1973)

Table 28 (Cont.)

DRINKING WATER QUALITY LIMITS
COMPARED WITH TRACT C-a GROUND WATER QUALITY

	E.P.A. I.P.R. M.C.L.'s	USPHS Limits	Projected Quality Dewatering Wells Mean+	All Samples Upper Aquifer	
				Mean+	Probability[1] Limit Exceeded
Arsenic (mg/l)	0.05	0.05	<0.01	0.01	45
Barium (mg/l)	1.00	1.00	<1.00	<1	0
Cadmium (mg/l)	0.01	0.01	<0.01	0.009	45
Chloride (mg/l)		250	10.5	12.0	0
Chromium (mg/l)	0.05	0.05	<0.01	<0.01	0
Copper (mg/l)		1.00	<0.06	0.073	40
Cyanide (mg/l)		0.20	<0.01	0.01	0
Fluoride (mg/l)	2.4	2.40	0.69	0.41	9
Iron (mg/l)		0.30	1.70	5.01	100
Lead (mg/l)	0.05	0.05	0.14	0.17	80
Manganese (mg/l)		0.05	0.15	0.13	85
Mercury (mg/l)	0.002		0.004		
Nitrate (mg/l)	45.00	45.00	0.26	0.21	0
Selenium (mg/l)	0.01	0.01	<0.01	<0.01	0
Silver (mg/l)	0.05	0.05	0.01	0.01	2
Sodium (mg/l)#		115.00	180.00	212.00	99
Sulfate (mg/l)		250.00	300.00	325.00	74
TDS (mg/l)		500.00	874.00	905.00	99
Zinc (mg/l)		5.00	0.30	0.26	0
Hardness (mg/l)#		500.00	371.00	328.00	25
Gross Alpha (pc/l)	15.00		2.90	3.50	10
Radium_{226} (pc/l)		3.00	*	0.17	0
Gross Beta (pc/l)	50.00		*	12.7	6
Strontium_{90} (pc/l)	8.00	10.00	*	*	*

1 - Percent of Times, + - Geometric Mean, # - Unestablished Limit, * - Insufficient Data

(R.B.O.S.C., Sept. 1977)

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Table 29

BASELINE GROUND WATER QUALITY SUMMARY

UPPER OIL SHALE AQUIFER

Param. No.	Item	High	Low	Geometric Mean	Geometric Deviation	No. of Analyses
410	Alkalinity (mg/l)	2390	70	408	1.35	144
1106	Aluminum (ug/l)	1000	<10	145	2.30	34
71846	Ammonia (NH_4) (mg/l)	1.8	< 0.1	0.3	2.31	121
1000	Arsenic (ug/l)	50	<10	10.30	1.20	142
1005	Barium (ug/l)	<1000	<100	<980	1.25	105
1010	Beryllium (ug/l)	<10	<10	<10		1
440	Bicarbonate (mg/l)	2760	85	482	1.43	144
1015	Bismuth (ug/l)					
310	BOD (mg/l)					
1020	Boron (ug/l)	4800	10	331	3.23	144
71870	Bromide (mg/l)	0.5	< 0.02	0.07	2.61	37
1025	Cadmium (ug/l)	100	< 1	9.6	1.39	140
915	Calcium (mg/l)	260	4	34.8	3.07	144
445	Carbonate (mg/l)	335	< 0.1	0.88	73.94	144
940	Chloride (mg/l)	87	< 0.1	12.04	2.00	144
1030	Chromium (ug/l)	<50	<10	11.90	1.59	143
340	COD (mg/l)	400	< 0.1	17.7	4.69	39
31615	Coliform, Fecal (Col/100 ml)					
31501	Coliform, Total (Col/100 ml)					
80	Color (PCU)					
95	Conductivity, Spec. (umhos)	*4200	810	1267	1.25	144
1040	Copper (ug/l)	800	<10	73.6	2.41	144
720	Cyanide (mg/l)	0.1	< 0.01	0.01	1.31	141
300	Dissolved Oxygen (mg/l)					
950	Fluoride (mg/	60	0.1	0.41	3.84	144
1120	Gallium (ug/l)					
1125	Germanium (ug/l)					
900	Hardness (Ca, Mg) (mg/l)	1110	32	328	1.94	124
1046	Iron (ug/l)	36000	< 5	5016	4.15	144
625	Kjeldahl Nitrogen (mg/l)					
1049	Lead (ug/l)	3800	2	173	5.27	144
1130	Lithium (ug/l)	1000	100	129.5	1.94	39
925	Magnesium (mg/l)	200	3.5	51.50	1.89	144
1056	Manganese (ug/l)	1700	<10	130.60	2.37	144
38260	MBAS (mg/l)					
71890	Mercury (ug/l)	45	< 1	3.58	2.78	144
1060	Molybdenum (ug/l)	1800	<50	130	2.34	20
1065	Nickel (ug/l)	200	< 1	18.9	1.67	104
71851	Nitrate (NO_3) (mg/l)	7	< 0.01	0.21	2.59	125
613	Nitrogen - Nitrite as N (mg/l)	0.6	< 0.02	0.07	3.92	38
631	Nitrite Plus Nitrate (N)(mg/l)					
608	Nitrogen, Ammonia (mg/l)	1.8	0.20	0.51	2.03	19
607	Nitrogen, Organic (mg/l)					
1330	Odor (severity)					
550	Oil and Grease (mg/l)					
	Organic Carbon (mg/l)					
681	Dissolved	50	1.0	8.5	1.75	128
689	Suspended					
680	Total					
	Pesticides (ug/l)					
400	pH*	8.8	6.0	6.78	0.47	140
32730	Phenols (ug/l)	174	<1	2.51	4.62	39
	Phosphate (mg/l)					
660	Dissolved (PO_4)					
70507	Ortho (P)	1.00	0.09	0.10	1.21	142
665	Total (P)					
935	Potassium (mg/l)	11.0	<1.0	2.19	1.99	39
	Radioactivity					
1503	Gross Alpha (pc/l)	29.0	0.1	3.48	3.18	100
9503	Radium 226 (pc/l)	0.8	0.1	0.17	1.83	22
80030	Natural Uranium (ug/l)					
3501	Gross Beta (pc/l)	73.0	2.0	12.7	2.80	29
80050	SR^{90} (pc/l)					
3515	CE^{137} (pc/l)					
1145	Selenium (ug/l)	< 10	< 1	< 9.8	1.21	142
955	Silica (SiO_2)	58.0	< 0.1	25.6	2.02	142
1075	Silver (ug/l)	100.00	1	11.5	2.06	104
930	Sodium (mg/l)	1170	92	212.0	1.30	144
931	Sodium Adsorption Ratio					
540	Solids, Dissolved (mg/l)	2850	530	905	1.28	144
1080	Strontium (ug/l)	10500	100	2893	2.89	20
945	Sulfate (mg/l)	900	< 4	325	1.51	142
746	Sulfide (mg/l)	49	0.03	0.63	5.55	40
11	Temperature (°F)*	68.9	46.4	54.0	3.64	143
1100	Tin (ug/l)					
1150	Titanium (ug/l)					
70	Turbidity (JTU)					
1085	Vanadium (ug/l)	< 50	<50			1
1090	Zinc (ug/l)	15000	10	263.3	2.97	144
1160	Zirconium (ug/l)					

* Normal mean and standard deviation

(R.B.O.S.C., May 1977)

Table 30

BASELINE GROUND WATER QUALITY SUMMARY
LOWER OIL SHALE AQUIFER

Param. No.	Item	High	Low	Geometric Mean	Geometric Deviation	No. of Analyses
410	Alkalinity (mg/l)	4500	52	674	2.33	108
1106	Aluminum (mg/l)	1000	< 10	241	2.80	28
71846	Ammonia (NH_4) (mg/l)	9.6	0.02	0.59	2.45	89
1000	Arsenic (ug/l)	30	< 10	10	1.01	106
1005	Barium (ug/l)	< 1000	< 100	968	1.32	69
1010	Beryllium (ug/l)	< 100	< 100	--	--	1
440	Bicarbonate (mg/l)	3310	260	842	2.47	108
1015	Bismuth (ug/l)	--	--	--	--	--
310	BOD (mg/l)	--	--	--	--	--
1020	Boron (ug/l)	5700	10	841	4.35	108
71870	Bromide (mg/l)	< 0.1	< 0.02	< 0.05	2.23	34
1025	Cadmium (ug/l)	30	< 1	9.9	1.43	106
915	Calcium (mg/l)	98	0.80	8.8	2.21	108
445	Carbonate (mg/l)	710	< 0.1	68.83	2.33	108
940	Chloride (mg/l)	160.0	< 0.1	21.7	2.73	106
1030	Chromium (ug/l)	< 50	< 10	< 11.48	1.47	106
340	COD (mg/l)	92	< 0.1	12.9	3.65	38
31615	Coliform, Fecal (Col/100 ml)	--	--	--	--	--
31501	Coliform, Total (Col/100 ml)	--	--	--	--	--
80	Color (PCU)	--	--	--	--	--
95	Conductivity, Spec. (umhos)	5180	845	1459	1.78	108
1040	Copper (ug/l)	300	< 10	88.07	1.76	108
720	Cyanide (mg/l)	0.08	< 0.01	0.01	1.24	105
300	Dissolved Oxygen (mg/l)	--	--	--	--	--
950	Fluoride (mg/	85	0.3	14.69	3.38	108
1120	Gallium (ug/l)	--	--	--	--	--
1125	Germanium (ug/l)	--	--	--	--	--
900	Hardness (Ca, Mg) (mg/l)	630	20	109.5	2.35	89
1046	Iron (ug/l)	16200	< 50	781.1	6.58	108
625	Kjeldahl Nitrogen (mg/l)	--	--	--	--	--
1049	Lead (ug/l)	26000	3	208	4.89	108
1130	Lithium (ug/l)	600	100	126.2	1.63	38
925	Magnesium (mg/l)	105	1.9	20	2.56	108
1056	Manganese (ug/l)	800	50	75.4	1.82	108
38260	MBAS (mg/l)	--	--	--	--	--
71890	Mercury (ug/l)	< 10	< 1	2.43	2.49	108
1060	Molybdenum (ug/l)	200	< 50	100	1.25	20
1065	Nickel (ug/l)	< 100	< 1	< 23.2	2.28	71
71851	Nitrate (NO_3) (mg/l)	2	< 0.1	0.1	2.14	90
613	Nitrogen - Nitrite as N (mg/l)	0.60	< 0.20	0.07	3.93	37
631	Nitrite Plus Nitrate (N)(mg/l)	--	--	--	--	--
608	Nitrogen, Ammonia (mg/l)	3.2	0.40	1.18	1.77	18
607	Nitrogen, Organic (mg/l)	--	--	--	--	--
1330	Odor (severity)	--	--	--	--	--
550	Oil and Grease (mg/l)	--	--	--	--	--
	Organic Carbon (mg/l)					
681	Dissolved	73	3.0	10.5	1.58	100
689	Suspended	--	--	--	--	--
680	Total	--	--	--	--	--
	Pesticides (ug/l)					
400	pH*	8.9	6.0	7.16	0.48	107
32730	Phenols (ug/l)	1000	< 1	2.41	5.67	38
	Phosphate (mg/l)					
660	Dissolved (PO_4)	--	--	--	--	--
70507	Ortho (P)	1.00	< 0.10	0.11	1.44	106
665	Total (P)	--	--	--	--	--
935	Potassium (mg/l)	15.0*	< 1.0	2.64	2.19	38
	Radioactivity					
1503	Gross Alpha (pc/l)	30.0	0.1	3.31	3.00	78
9503	Radium 226 (pc/l)	0.9	0.09	0.31	2.06	23
80030	Natural Uranium (ug/l)	--	--	--	--	--
3501	Gross Beta (pc/l)	830.0	2.0	21.4	3.13	38
80050	SR^{90} (pc/l)	--	--	--	--	--
3515	CE^{137} (pc/l)	--	--	--	--	--
1145	Selenium (ug/l)	< 100	< 10	< 10.2	1.25	108
955	Silica (SiO$_2$)	60.0	< 0.1	10.1	2.41	108
1075	Silver (ug/l)	100	< 1	8.9	1.40	66
930	Sodium (mg/l)	1560	155	397	2.12	108
931	Sodium Adsorption Ratio	--	--	--	--	--
540	Solids, Dissolved (mg/l)	3640	540	1075	1.97	108
1080	Strontium (ug/l)	3500	200	680	2.21	20
945	Sulfate (mg/l)	560	< 4	112	3.40	108
746	Sulfide (mg/l)	6.50	< 0.01	0.56	3.97	38
11	Temperature (°F)*	75.2	46.9	58.5	3.57	106
1100	Tin (ug/l)	--	--	--	--	--
1150	Titanium (ug/l)	--	--	--	--	--
70	Turbidity (JTU)	--	--	--	--	--
1085	Vanadium (ug/l)	< 50.00	< 50.00	--	--	--
1090	Zinc (ug/l)	68000	20	239.2	3.80	106
1160	Zirconium (ug/l)	--	--	--	--	--

* Normal mean and standard deviation

(R.B.O.S.C., May 1977)

Table 31

Results of Statistical (t, F and t') Test Comparison of Baseline and MDF Means for Upper and Lower Aquifer Water. Constituents Listed are Those for Which the Null Hypothesis of Equality of Means was Rejected

	Station or Stations Compared to Baseline							
	Upper Aquifer							Lower Aquifer
Constituent	All[1] Wells[2]	AM-3[3]	G-S M 1	G-S M 2	G-S M 3	G-S M 4	G-S 15 U	G-S 15L
Sp. Conductance	>			>	>	>	>	>
TDS	>			>		>	>	
pH	>	>	>	>	>	>	>	>
Alkalinity		<	<			>		
Temperature		<			<			>
Sodium					>		>	>
Calcium					<	>	>	<
Magnesium	>		<			>	>	>
Carbonate	>	>			>			
Bicarbonate			<		<	>	>	
Sulfate	>	<		>			>	>
Chloride	>				>			
Fluoride		>	<		>	<		
Silicon Dioxide	<	<		<	<			<
Boron	<		<	<		<		
Aluminum				<	>	<		
Bromide	>				>		>	>
Chromium	<			<	<	<	<	<
Iron	<		<	<	<	<	<	<
Lead	<			<	<	<	<	<
Mercury	<			<	<	<	<	<
Nickel	<							
Strontium	<					<		<
Zinc	<			<			<	<
Sulfide	<			<	<	<	<	
Ammonia-N					<			
Phenols					<			
COD								>

[1] Means of all upper aquifer wells in environmental monitoring program compared to baseline upper aquifer mean concentrations.

[2] > and < symbols indicate test results showing difference in means of baseline and report period; < indicates that report period mean is less than baseline; > indicates report period mean greater than baseline.

[3] Blank in table indicates that means tested not different.

(R.B.O.S.C., Mar. 1980)

Table 32

SUMMARY OF WET CHEMICAL WATER ANALYSIS
UPPER, LOWER, AND COMBINED AQUIFERS
TRACT C-a AND VICINITY

	Lower Aquifer				Upper Aquifer				Combined Aquifer			
	From Monitoring & Pumping				From Drilling, Monitoring, & Pumping				From Drilling			
Item	Low	High	Average	No. Items Avg.	Low	High	Average	No. Items Avg.	Low	High	Average	No. Items Avg.
Aluminum	-0.100	1.600	0.120	45	-0.100	2.200	0.176	46	-0.100	0.100	0.005	21
Ammonia	-0.100	5.600	0.601	79	-0.100	10.600	0.766	100	-0.100	3.000	0.974	28
Arsenic	-0.050	0.050	0.001	99	-0.050	0.200	0.005	111	-0.100	0.500	0.038	30
Bicarbonate	-0.100	11800.000	1143.114	114	-0.100	2690.000	625.259	139	350.000	19600.000	2073.000	58
Cadmium	-0.010	0.030	0.002	100	-0.010	0.030	0.002	95	-0.010	0.070	0.009	24
Calcium	-1.000	515.000	48.877	114	3.100	780.000	72.984	139	0.100	88.000	26.290	58
Carbonate	-1.000	3160.000	97.721	114	-0.100	1190.000	34.368	138	-0.100	3000.000	163.982	57
Chloride	-1.000	205.000	37.952	114	-1.000	240.000	29.194	139	3.000	6600.000	238.352	58
Chromium	-0.050	0.010	0.000	95	-0.050	0.500	0.009	96	-0.050	0.570	0.057	24
Copper	-0.100	0.200	0.014	100	-0.100	0.780	0.024	95	-0.100	0.100	0.004	24
Fluoride	-0.050	120.000	13.347	115	0.060	80.000	4.993	139	0.200	60.000	12.869	58
Hydroxide	-0.100	890.000	221.250	8	-0.100	380.000	9.268	41	-0.100	-0.100	0.0	30
Iron	-0.050	33.000	2.343	114	-0.050	16.000	1.841	123	-0.050	16.000	0.685	51
Lead	-0.050	4.600	0.285	100	-0.050	3.400	0.287	95	-0.050	0.500	0.065	24
Magnesium	-1.000	140.000	39.154	114	-0.100	140.000	48.330	138	0.700	96.000	27.265	57
Mercury	-0.010	0.002	0.000	96	-0.010	0.045	0.001	98	-0.010	-0.010	0.0	16
Nitrate	-0.100	55.000	0.977	114	-0.100	5.000	0.456	139	-0.100	15.000	1.152	58
Phosphate	-0.100	2.400	0.060	101	-0.100	9.200	0.288	98	-0.100	8.200	2.425	24
Potassium	-1.000	84.000	26.800	5	-1.000	93.000	12.773	41	-1.000	76.000	15.167	30
Selenium	-0.010	-0.001	0.0	100	-0.100	0.010	0.000	112	-0.100	0.010	0.000	30
Silicon Dioxide	-0.100	50.000	12.675	114	-0.100	58.000	25.737	139	6.400	41.000	17.790	58
Sodium	86.000	5290.000	552.026	114	40.000	1170.000	274.381	139	165.000	12000.000	1007.276	56
Sulfate	-5.000	740.000	244.522	114	-4.000	800.000	324.547	139	-4.000	535.000	180.534	58
Sulfide	-0.010	2.400	1.467	3	-1.000	4.100	1.556	18	-1.000	12.000	2.753	19
Zinc	-0.500	10.000	0.537	100	-0.500	4.400	0.409	86	-0.500	1.000	0.286	14
Gross Alpha	0.300	23.000	7.486	22	0.900	10.000	4.500	21	0.500	12.000	6.675	8
Gross Beta	4.000	260.000	40.545	11	13.000	38.000	22.333	3	1.000	57.000	26.229	7
Hardness	20.000	1260.000	281.131	114	32.000	1870.000	379.503	139	30.000	520.000	175.000	57
Ph	6.000	12.200	7.328	114	6.000	10.200	7.142	139	6.800	8.800	7.904	57
Conductance	760.000	15800.000	2469.750	112	675.000	6200.000	1518.623	138	880.000	28000.000	3426.754	57
Diss. Solids	430.000	12200.000	1682.257	113	425.000	3140.000	1165.762	139	650.000	30700.000	2869.509	57
Manganese	-0.050	0.400	0.058	108	-0.100	0.780	0.099	111	-0.200	0.320	0.018	40
Alkalinity	-0.100	10480.000	965.895	109	-0.100	2360.000	530.599	97	31.000	9310.000	1069.629	27
Cyanide	-0.100	-0.010	0.0	94	-0.010	-0.010	0.0	70	--	--	0.0	0
Boron	-0.100	25.000	2.130	97	-0.100	4.400	0.760	82	-0.100	1.500	0.620	10
Barium	-1.000	-0.100	0.0	95	-1.000	-1.000	0.0	71	--	--	0.0	0
Silver	-0.010	0.110	0.006	95	-0.010	0.100	0.012	71	--	--	0.0	0
Nickel	-0.100	0.100	0.020	93	-0.010	0.200	0.024	71	--	--	0.0	0
Lithium	--	--	0.0	0	-0.500	-0.500	0.0	2	--	--	0.0	0
TOC	2.000	37.000	9.227	44	-1.000	27.000	7.477	44	--	--	0.0	0

(R.B.O.S.C., July 1975)

Table 33

SUMMARY OF QUALITATIVE SPECTOGRAPHIC ANALYSIS

	Lower Aquifer From Monitoring & Pumping				Upper Aquifer From Drilling, Monitoring and Pumping				Combined Aquifer From Drilling			
Item	Low	High	Average	No. Items Avg.	Low	High	Average	No. Items Avg.	Low	High	Average	No. Items Avg.
Aluminum	0.010	1.000	0.199	45	0.010	1.000	0.172	74	0.010	1.000	0.182	50
Antimony	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Arsenic	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Barium	0.001	0.100	0.042	9	0.001	0.050	0.015	6	0.100	0.100	0.100	1
Beryllium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Bismuth	--	--	0.0	0	--	--	0.0	0	0.100	0.100	0.100	1
Boron	0.050	99999.000	0.608	45	-0.020	5.000	0.350	74	0.050	5.000	0.456	53
Cadmium	99999.000	99999.000	0.0	0	99999.000	99999.000	0.0	0	--	--	0.0	0
Calcium	5.000	99999.000	8.000	5	1.000	99999.000	5.500	2	2.000	99999.000	5.500	4
Cerium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Cesium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Chromium	0.010	0.010	0.010	1	0.000	0.050	0.010	13	0.001	0.050	0.012	13
Cobolt	--	--	0.0	0	0.001	0.001	0.001	1	--	--	0.0	0
Columbium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Copper	0.001	0.100	0.012	37	0.000	0.050	0.014	45	0.000	0.050	0.006	30
Dysprosium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Erbium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Europium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Gadolinium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Gallium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Germanium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Gold	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Hafnium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Holmium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Indium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Iridium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Iron	0.005	5.000	0.341	47	0.010	1.000	0.130	72	0.010	10.000	0.518	50
Lanthanum	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Lead	0.050	0.050	0.050	3	0.001	0.500	0.094	8	0.005	0.500	0.129	9
Lithium	0.001	5.000	0.179	32	-0.500	0.200	0.056	43	-0.500	1.000	0.153	36
Lutetium	--	--	0.0	0	--	--	0.0-	0	--	--	0.0	0
Magnesium	5.000	99999.000	5.714	7	5.000	99999.000	8.000	5	1.000	99999.000	6.750	12
Manganese	0.001	0.100	0.017	32	0.001	1.000	0.057	41	0.010	10.000	0.570	22
Mercury	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Molybdenum	0.001	0.010	0.003	18	0.001	0.050	0.007	32	0.001	0.061	0.012	28
Neodymium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Nickel	--	--	0.0	0	0.001	0.010	0.005	2	--	--	0.0	0
Osmium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Palladium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Platinum	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Potassium	0.010	99999.000	2.214	40	0.050	99999.000	1.409	59	0.100	99999.000	1.538	42
Praseodymium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Radium	0.400	0.400	0.400	1	0.100	0.300	0.175	4	0.300	0.500	0.400	3
Rhenium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Rhodium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Rubidium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Ruthenium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Samarium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Scandium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Selenium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Silicon	-0.500	99999.000	8.023	44	2.000	50.000	16.932	74	5.000	99999.000	16.245	53
Silver	0.000	0.001	0.001	10	-0.001	0.001	0.000	11	0.000	0.000	0.000	3
Sodium	0.100	99999.000	5.025	4	2.000	99999.000	5.667	3	99999.000	99999.000	0.0	0
Strontium	0.010	1.000	0.197	40	0.100	1.000	0.215	53	0.100	0.500	0.185	34
Tantalum	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Terbium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Thallium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Thorium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Thulium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Tin	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Titanium	0.001	0.050	0.008	27	0.001	0.150	0.021	45	0.001	0.200	0.020	38
Tungsten	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Uranium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Vanadium	--	--	0.0	0	0.001	0.100	0.027	16	0.001	0.050	0.019	19
Ytterbium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Yttrium	--	--	0.0	0	--	--	0.0	0	--	--	0.0	0
Zinc	0.001	0.500	0.117	9	0.010	0.500	0.144	5	0.005	0.100	0.041	4
Zirconium	--	--	0.0	0	--	--	--	0	--	--	0.0	0

(R.B.O.S.C., July 1975)

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Table 34

SUMMARY OF WET CHEMICAL ANALYSIS MONITORING PROGRAM
UPPER AND LOWER AQUIFER
TRACT C-a AND VICINITY
Values in mg/l
MARCH 1975 TO NOVEMBER 1976

	Lower Aquifer					Upper Aquifer				
Item	Low	High	Average	# Items Averaged	Std. Dev.	Low	High	Average	# Items Averaged	Std. Dev.
Alkalinity	52.000	4500.000	975.927	123	788.577	70.000	2390.000	530.878	168	443.722
Aluminum	- 0.010	1.000	0.300	33	0.297	- 0.010	1.000	0.142	41	0.214
Ammonia	0.020	9.600	0.724	101	1.012	- 0.100	1.800	0.426	142	0.352
Arsenic	- 0.010	0.030	0.000	123	0.003	- 0.010	0.050	0.001	167	0.006
Barium	- 0.100	1.000	0.012	81	0.111	- 0.100	- 1.000	0.000	125	0.000
Bicarbonate	260.000	3310.000	1108.374	123	815.660	85.000	2760.000	615.553	168	494.654
Boron	- 0.010	9.400	1.301	123	1.530	- 0.010	4.800	0.622	168	0.939
Bromide	- 0.020	0.400	0.018	38	0.068	- 0.020	0.500	0.062	43	0.121
Chemical Oxygen Demand	- 0.100	92.000	22.941	44	18.900	- 0.100	400.000	48.233	45	75.591
Cadmium	- 0.001	0.030	0.002	123	0.006	- 0.001	0.001	0.002	168	0.009
Calcium	0.800	98.000	16.078	123	18.451	- 0.010	260.000	60.010	168	54.976
Carbonate	- 0.100	710.000	90.715	123	113.104	- 0.100	335.000	26.388	168	48.740
Chloride	- 0.100	185.000	32.997	123	33.331	- 0.100	87.000	17.857	168	16.393
Chromium	- 0.010	- 0.050	0.004	121	0.009	- 0.010	0.050	0.003	167	0.010
Conductivity (umhos/cm)	845.000	6000.000	2019.98	122	1172.06	810.000	4200.000	1591.623	167	741.923
Copper	- 0.010	0.300	0.018	123	0.050	- 0.010	0.800	0.021	168	0.098
Cyanide	- 0.010	0.080	0.002	122	0.009	- 0.010	9.100	0.002	167	0.012
Dissolved Oxygen Demand	3.000	73.000	12.143	92	8.656	1.000	50.000	10.133	129	7.208
Dissolved Solids	540.000	3640.000	1419.715	123	793.393	530.000	2850.000	1129.470	168	506.343
Fluoride	0.200	85.000	15.942	123	15.700	0.100	60.000	2.906	168	8.479
Gross Alpha (pci/l)	0.100	30.000	5.741	71	6.080	0.200	29.000	5.334	97	5.144
Gross Beta (pci/l)	3.000	830.000	50.583	36	134.942	2.000	73.000	22.464	28	18.558
Hardness (total)	20.000	690.000	165.861	101	153.023	32.000	1110.000	392.648	145	234.534
Iron	- 0.050	16.200	2.720	123	3.625	- 0.005	36.000	4.970	168	5.335
Lead	0.003	26.000	0.822	123	2.977	0.002	3.800	0.352	168	0.534
Lithium	- 0.100	1.000	0.109	44	0.197	- 0.100	1.000	0.122	45	0.280
Magnesium	1.900	140.000	30.581	123	28.439	3.500	200.000	59.421	168	37.088
Manganese	- 0.050	0.800	0.086	123	0.118	- 0.010	1.700	0.187	168	0.211
Mercury	- 0.001	- 0.010	0.000	123	0.000	- 0.001	0.045	0.000	168	0.004
Nickel	- 0.001	0.100	0.075	81	0.018	- 0.001	0.200	0.026	125	0.027
Nitrate	- 0.100	2.000	0.329	102	0.391	- 0.010	7.000	0.581	146	1.110
Nitrate -N	- 0.020	0.600	0.149	43	0.198	- 0.020	0.600	0.157	44	0.192
pH	6.000	11.000	7.27	120	0.675	6.000	8.800	6.816	165	0.463
Phenols	- 0.001	1.000	0.034	44	0.152	- 0.001	0.174	0.010	45	0.029
Phosphate	- 0.109	1.000	0.041	123	0.138	- 0.010	1.000	0.018	168	0.093
Potassium	- 1.000	19.000	4.252	44	4.193	- 1.000	11.000	2.922	45	2.459
Selenium	- 0.010	- 0.100	0.000	123	0.000	- 0.001	- 0.010	0.000	168	0.000
Silicon Dioxide	- 0.100	60.000	10.072	123	8.323	- 0.100	58.000	25.622	168	15.643
Silver	- 0.001	0.100	0.002	79	0.011	- 0.001	0.100	0.006	123	0.019
Sodium	155.000	1560.000	530.122	123	381.347	37.000	1170.000	273.167	168	221.695
Sulfate	- 4.000	740.000	163.610	123	151.638	- 4.000	900.000	357.024	168	185.697
Sulfide	- 0.010	6.500	1.036	44	1.212	0.030	49.000	3.301	46	9.714
Zinc	0.020	68.000	1.163	123	6.275	- 0.010	15.000	0.679	168	1.494

(1) Less than detectable limit given.

(R.B.O.S.C., Nov. 1976)

Table 35

SUMMARY OF SPECTROGRAPHIC ANALYSIS MONITORING PROGRAM
UPPER AND LOWER AQUIFER
TRACT C-a and VICINITY
Values in mg/l
MARCH 1975 to AUGUST 1976

	Lower Aquifer					Upper Aquifer				
Item	Low	High	Average	# Items Avg'd.	Std. Dev.	Low	High	Average	# Items Avg'd.	Std. Dev.
Aluminum	0.001	1.000	0.065	101	0.122	0.001	1.000	0.114	146	0.189
Antimony	0.200	0.200	0.200	1	0.000	---	---	---	0	---
Arsenic	---	---	---	0	---	---	---	---	0	---
Barium	0.001	0.100	0.003	14	0.004	0.001	0.010	0.003	23	0.004
Beryllium	---	---	---	0	---	---	---	---	0	---
Bismuth	---	---	---	0	---	---	---	---	0	---
Boron	0.100	0.500	0.359	99	0.165	0.100	2.000	0.366	146	0.235
Cadmium	Major	Major		0		Major	Major		0	
Calcium	0.100	Major	5.837	24	3.891	1.000	Major	7.882	17	3.533
Cerium	---	---	---	0	---	---	---	---	0	---
Cesium	---	---	---	0	---	---	---	---	0	---
Chromium	---	---	---		---	---	---	---	0	---
Cobalt	---	---	---	0	---	---	---	---	0	---
Columbium	---	---	---	0	---	---	---	---	0	---
Copper	0.001	0.020	0.005	92	0.005	0.001	0.020	0.006	136	0.005
Dysprosium	---	---	---	0	---	---	---	---	0	---
Erbium	---	---	---	0	---	---	---	---	0	---
Europium	---	---	---	0	---	---	---	---	0	---
Gadolinium	---	---	---	0	---	---	---	---	0	---
Gallium	---	---	---	0	---	---	---	---	0	---
Germanium	---	---	---	0	---	---	---	---	0	---
Gold	---	---	---	0	---	---	---	---	0	---
Hafnium	---	---	---	0	---	---	---	---	0	---
Holmium	---	---	---	0	---	---	---	---	0	---
Indium	---	---	---	0	---	---	---	---	0	---
Iridium	---	---	---	0	---	---	---	---	0	---
Iron	0.010	0.500	0.048	99	0.087	0.010	2.000	0.118	145	0.251
Lanthanum	---	---	---	0	---	---	---	---	0	---
Lead	---	0.500	0.032	30	0.096	0.001	0.200	0.020	41	0.044
Lithium	0.001	0.100	0.011	74	0.020	0.001	0.500	0.014	100	0.053
Lutetium	0.100	0.010	0.010	1	0.000	0.001	0.010	0.005	2	0.006
Magnesium	0.100	Major	3.509	23	3.471	0.100	Major	6.006	78	4.290
Manganese	0.001	0.100	0.013	83	0.025	0.001	0.200	0.020	128	0.036
Mercury	---	---	---	0	---	---	---	---	0	---
Molybdenum	0.001	0.100	0.010	52	0.018	0.001	0.500	0.017	82	0.077
Neodymium	---	---	---	0	0.000	---	---	---	0	---
Nickel	0.001	0.001	0.001	1	0.000	0.001	0.001	0.001	2	0.000
Osmium	---	---	---	0	---	---	---	---	0	---
Palladium	---	---	---	0	---	---	---	---	0	---
Platinum	---	---	---	0	---	---	---	---	0	---
Potassium	0.010	5.000	0.873	98	1.083	0.010	5.000	0.903	143	1.116
Praseodymium	---	---	---	0	---	---	---	---	0	---
Radium (pci/l)	0.090	0.900	0.387	23	0.257	0.100	0.800	0.200	26	0.160
Rhenium	---	---	---	0	---	---	---	---	0	---
Rhodium	---	---	---	0	---	---	---	---	0	---
Rubidium	---	---	---	0	---	---	---	---	0	---
Ruthenium	---	---	---	0	---	---	---	---	0	---
Samarium	---	---	---	0	---	---	---	---	0	---
Scandium	---	---	---	0	---	---	---	---	0	---
Selenium	---	---	---	0	---	---	---	---	0	---
Silicon	<0.500	10.000	4.317	101	2.121	1.000	20.000	5.082	146	3.739
Silver	---	0.001	0.001	7	0.000	---	0.001	0.001	13	0.000
Sodium	0.100	Major	7.490	92	2.716	2.000	Major	7.385	104	2.397
Strontium	0.001	1.000	0.096	32	0.102	0.001	1.000	0.108	136	0.094
Tantalum	---	---	---	0	---	---	---	---	0	---
Terbium	---	---	---	0	---	---	---	---	0	---
Thallium	---	---	---	0	---	---	---	---	0	---
Thorium	---	---	---	0	---	---	---	---	0	---
Thulium	---	---	---	0	---	---	---	---	0	---
Tin	---	0.001	0.001	2	0.001	0.001	0.001	0.001	1	0.000
Titanium	0.001	0.010	0.000	41	0.004	0.001	0.020	0.004	79	0.004
Tungsten	---	---	---	0	---	---	---	---	0	---
Uranium	<1.500	<1.500		1	0.000	---	---	---	0	---
Vanadium	---	---	---	0	---	---	0.001	0.001	1	0.000
Ytterbium	---	---	---	0	---	---	---	---	0	---
Yttrium	---	---	---	0	---	---	---	---	0	---
Zinc	0.001	0.200	0.012	22	0.110	0.001	0.200	0.013	44	0.036
Zirconium	---	---	---	0	---	---	---	---	0	---

--- Less than minimum detectable amount
Major - Concentration too large to quantify (see wet chemical analysis)

(R.B.O.S.C., Nov. 1976)

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Table 36

REINJECTION WATER QUALITY SUMMARY (RAW WATER)

(All values listed are geometric mean)

Param. No.	Item	1 Dewatering Wells	2 Drilling Effluent	3 Corral Gulch E. of Tract	4 Piceance Creek	5 Black Sulphur
410	Alkalinity (mg/l)	371	263	404	532	482
1106	Aluminum (mg/l)		.15	.02		.01
71846	Ammonia (NH_4) (mg/l)	.3	.70	.03		
1000	Arsenic (ug/l)	< 10.1	14.2	5.3		0
1005	Barium (ug/l)	< 1002		< 74		0
1010	Beryllium (ug/l)			< 3.3		
440	Bicarbonate (mg/l)	429	455	492	649	588
1015	Bismuth (ug/l)			< 10		
310	BOD (mg/l)			2.5		
1020	Boron (ug/l)	258	470	117		180
71870	Bromide (mg/l)			.10		.05
1025	Cadmium (ug/l)	< 10	10.7	3.4		
915	Calcium (mg/l)	54	70	86	79	120
445	Carbonate (mg/l)	< 1.8	4.6	0	0	0
940	Chloride (mg/l)	10.5	23.8	9.8	16.1	11
1030	Chromium (ug/l)	< 11	31	2.8		
340	COD (mg/l)	32		13.6		
31615	Coliform, Fecal (Col/100 ml)			2.1		
31501	Coliform, Total (Col/100 ml)			323		
80	Color (PCU)			4.5		
95	Conductivity, Spec. (umhos)	1227	1148	1231		1680
1040	Copper (ug/l)	< 63	<100	2.2		
720	Cyanide (mg/l)	<.01		.01		
300	Dissolved Oxygen (mg/l)			8.3		
950	Fluoride (mg/l)	.69	1.15	.49	.78	.6
1120	Gallium (ug/l)			< 4.6		
1125	Germanium (ug/l)		10.7	< 12.4		
900	Hardness (Ca, Mg) (mg/l)	371	393	476	538	
1046	Iron (ug/l)	1708	95	31	41	6900
625	Kjeldahl Nitrogen (mg/l)			.4		
1049	Lead (ug/l)	141	55	1.9		< 50
1130	Lithium (ug/l)	118		11.6		10
925	Magnesium (mg/l)	51	53	62	82	95
1056	Manganese (ug/l)	146	57	17	38	290
38260	MBAS (mg/l)			.55		
71890	Mercury (ug/l)	3.5	< 10	.02		
1060	Molybdenum (ug/l)			37		
1065	Nickel (ug/l)	18.5		<8.6		
71851	Nitrate (NO_3) (mg/l)	.26	.14	1.22		
613	Nitrogen - Nitrite as N (mg/l)	.07		.02		
631	Nitrite Plus Nitrate (N)(mg/l)			.32	.27	.66
608	Nitrogen, Ammonia (mg/l)			.03		
607	Nitrogen, Organic (mg/l)			.29		
1330	Odor (severity)			0		
550	Oil and Grease (mg/l)			2.9		
	Organic Carbon (mg/l)					
681	Dissolved	10.1		8.1		
689	Suspended			.4		
680	Total			11.4		
	Pesticides (ug/l)			0		
400	pH*	6.58	7.26	7.88	8.0	
32730	Phenols (ug/l)	< 3.66		.05		
	Phosphate (mg/l)					
660	Dissolved (PO_4)			.06		
70507	Ortho (P)	<.10	.32	.02	.03	.04
665	Total (P)			.03		
935	Potassium (mg/l)	2.2	3.9	1.6	3.3	2.8
	Radioactivity					
1503	Gross Alpha (pc/l)#	2.9	4.2	< 6.6		
9503	Radium 226 (pc/l)			.07		
80030	Natural Uranium (ug/l)			< 9.7		
3501	Gross Beta (pc/l)					
80050	SR^{90} (pc/l)			3.1		
3515	CE^{137} (pc/l)			3.0		
1145	Selenium (ug/l)		<10	3.0		3
955	Silica (SiO_2)	24.2	29.4	21.1	17.6	20
1075	Silver (ug/l)	14.4		<1.5	34	
930	Sodium (mg/l)	180.3	189.4	109.2	184	150
931	Sodium Adsorption Ratio			2.2		
540	Solids, Dissolved (mg/l)	874	994	823	1086	1210
1080	Strontium (ug/l)			1685		3600
945	Sulfate (mg/l)	300	326	289	379	520
746	Sulfide (mg/l)	1.0	1.0	.06		
11	Temperature (°F)*	51.7	65.1	52.5	39.7	
1100	Tin (ug/l)			<9.7		
1150	Titanium (ug/l)			<6.0		
70	Turbidity (JTU)			8.2		
1085	Vanadium (ug/l)			6.8		
1090	Zinc (ug/l)	298	408	12.5		
1160	Zirconium (ug/l)			<18.4		

* Normal mean and standard deviation

# Calculated from gross alpha as natural uranium

(R.B.O.S.C., Sept. 1977)

Table 37.

WELL SUMMARY TO ESTIMATE COMPATIBILITY

	CE-707	CE-708	TO-2	G-S 2-3	G-S 4-5	AM-3	CE-705A	G-S 6	Pumped CE-705A	Weighted Average[1]	Corral Gulch E[2]	Piceance Creek[3]
Sodium (mg/l)	200	173	198	188	255	175	150	209	197	180	109	184
Calcium (mg/l)	125	70	60	24	17	13	38	16	65	54	85	79
Magnesium (mg/l)	38	51	61	67	28	28	56	29	67	51	62	51
Bicarbonate (mg/l)	612	470	553	386	420	243	340	520	548	429	492	588
Carbonate (mg/l)	0	0	0	62	5	28	36	50	0	2	0	0
Sulfate (mg/l)	343	309	311	288	285	266	270	320	302	300	289	520
Chloride (mg/l)	14	14	17	9	5	15	4	6	5	11	9	16
pH (units)	64	6.6	6.7	7.0	7.2	7.0	6.4	7.7	6.6	6.6	7.9	8.0
TDS (mg/l)	1072	898	966	874	851	688	730	679	991	874	823	1086
Temp. (^{o}F)	53	53	53	53	55	50	50	53	56	52		
H_2O Depth (ft.)	259	50	115	106	68	37	28	55	165			

1 Projected quality of dewatering wells and mine seepage
2 Projected quality of on-site imported water
3 Projected quality of off-site imported water

(R.B.O.S.C., Sept. 1977)

Table 38

Analytical and Consulting Chemists
2600 WEST 29TH AVENUE
DENVER, COLORADO 80211
ANALYSIS REPORT
TELEPHONE 455-3641

DATE RECEIVED:
DATE REPORTED:

LAB. NUMBER:

SAMPLES ARE DISCARDED IN 15 DAYS FROM DATE (
REPORT UNLESS WE ARE REQUESTED, IN WRITI
TO RETAIN THEM FOR A LONGER PERIOD. PERIS
ABLE SAMPLES ARE USUALLY DISCARDED IMM
IATELY UNLESS CLIENT HAS REQUESTED SPECI
HANDLING (FREEZING, ETC.) IN ADVANCE.

SAMPLE MARKED: APPROXIMATE MINIMUM & DETECTABLE

ANALYSIS: Qualitative Spectrographic Analysis

Figures are ________ Estimates

		Phosphorus	0.1
Antimony	.005	Molybdenum	.005
Arsenic	.01	Neodymium	.01
Aluminum	.005	Nickel	.005
Boron	.005	Osmium	.05
Barium	.01	Palladium	.005
Beryllium	.001	Potassium	.05
Bismuth	.001	Praseodymium	.01
Calcium	.001	Platinum	.005
Columbium	.01	Radium	
Cadmium	.005	Rubidium	.05
Cerium	.01	Rhenium	.005
Cobalt	.005	Rhodium	.01
Chromium	.001	Ruthenium	.01
Caesium	.05	Scandium	.02
Copper	.001	Silicon	.001
Dysprosium	.01	Samarium	.01
Erbium	.01	Strontium	.005
Europium	.01	Silver	.001
Gallium	.005	Sodium	.005
Gadolinium	.005	Tantalum	.02
Germanium	.005	Terbium	.1
Gold	.005	Thallium	.02
Hafnium	.01	Thulium	.01
Holmium	.01	Thorium	.05
Indium	.005	Tin	.001
Iron	.001	Titanium	.001
Iridium	.02	Tungsten	.01
Lanthanum	.01	Uranium	.1
Lead	.005	Vanadium	.001
Lithium	.001	Yttrium	.005
Lutecium	.01	Ytterbium	.005
Magnesium	.005	Zinc	.01
Manganese	.005	Zirconium	.005
Mercury	.1		

Multiply by 10 to obtain
parts per million

MEMBERS OF:

AMERICAN ASS'N OF CEREAL CHEMISTS
AMERICAN CHEMICAL SOCIETY
AMERICAN OIL CHEMISTS' SOCIETY
ASS'N OF OFFICIAL RACING CHEMISTS
BAKERY ENGINEERS OF AMERICA
INSTITUTE OF FOOD TECHNOLOGY
SIGMA XI

THE INDUSTRIAL LABORATORIES COMPAN

____
CHEMIST

THIS REPORT IS NOT TO BE REPRODUCED, IN WHOLE OR IN PART, FOR ADVERTISING PURPOSES WITHOUT OBTAINING PRIOR WRITTEN AUTHORIZATI

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[redacted]

Table 39

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            UNITED STATES DEPARTMENT OF THE INTERIOR
                       GEOLOGICAL SURVEY
             CENTRAL LABORATORY, SALT LAKE CITY, UTAH

                     WATER QUALITY ANALYSIS
                 LAB ID # 32607 RECORD # 45457

SAMPLE LOCATION: NO INFORMATION IN STATION HEADER FILE <---              MAIL TO LAKEWOOD COLO
STATION ID: 395530108312700    LAT.LONG.SEQ.:                            SCHEDULES USED:  364    1    0    0
DATE OF COLLECTION: BEGIN--750129  END--          TIME--1100             NUMBER OF DETERMINATIONS: 27
COUNTY CODE: 103   PROJECT IDENTIFICATION: C00640                        COST OF ANALYSIS $  85.65      DUP--750219
CATA TYPE: 2  SOURCE: GROUND WATER        GEOLOGIC UNIT: 124GRRV         SUBMIT CORRECTIONS TO CENTRAL LAB WITHIN
COMMENTS:                                                                  15 DAYS FROM BELOW STAMPED DATE. INDICA
   COLL BY G SAULNES FIELD VALUE USED FOR PH AND COND                      CENTRAL LAB ID # AND RECORD # WITH RESPO
                                                                         WRD-QW FILE STORAGE REQUESTED. THE CENTRAL L
                                                                           ATTEMPTED TO SUPPLY HEADING INFORMATION TO
                                                                           STATION HEADER FILE. PLEASE CHECK OUR ATTE

ALK.TOT (AS CACO3)    MG/L      697      MAGNESIUM DISS         MG/L       48
  UMINUM DISSOLVED    UG/L        0      MANGANESE DISSOLVED    UG/L        0
 SENIC DISSOLVED      UG/L        3      NO2+NO3 AS N DISS      MG/L        0.02
BARIUM DISSOLVED      UG/L      100      PH                                 7.5
BICARBONATE           MG/L      850      PHOS ORTHO DIS AS P    MG/L        0.02
BORON DISSOLVED       UG/L      800      PHOSPHATE DIS ORTHO    MG/L        0.06
BROMIDE               MG/L        0.1    POTASSIUM DISS         MG/L        0.7
CALCIUM DISS          MG/L       55      RESIDUE DIS CALC SUM MG/L     1190
CHLORIDE DISS         MG/L       16      RESIDUE DIS TON/AFT                1.62
CONDUCTIVITY                   1725      SAR                                7.6
DEPTH(FT.FR.SURFACE)            800      SELENIUM DISSOLVED     UG/L        0
FLUORIDE DISS         MG/L        7.7    SILICA DISSOLVED       MG/L       19
HARDNESS NONCARB      MG/L        0      SODIUM DISS            MG/L      320
HARDNESS TOTAL        MG/L      340      SODIUM PERCENT                    67
IRON DISSOLVED        UG/L      210      STRONTIUM DISSOLVED    UG/L     2100
LEAD DISSOLVED        UG/L        2      SULFATE DISS           MG/L      300
LITHIUM DISSOLVED     UG/L       70      WATER TEMP (DEG C)                17.0
                                         ZINC DISSOLVED         UG/L       10

           CATIONS                                    ANIONS

                 (MG/L)        (MEQ/L)                      (MG/L)        (MEQ/L)
  CIUM DISS       55            2.745 BICARBONATE           850          13.932
MAGNESIUM DISS    48            3.949 CHLORIDE DISS          16           0.452
POTASSIUM DISS     0.7          0.018 FLUORIDE DISS           7.7         0.406
SODIUM DISS      320           13.920 SULFATE DISS          300           6.246
                                      NO2+NO3 AS N D          0.02        0.002
                             -------                                     -------
                    TOTAL     20.631                  TOTAL               21.036

                    PERCENT DIFFERENCE =   -0.97
```

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Table 40

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            UNITED STATES DEPARTMENT OF THE INTERIOR
                      GEOLOGICAL SURVEY
            CENTRAL LABORATORY, SALT LAKE CITY, UTAH

                    WATER QUALITY ANALYSIS
               LAB ID #  16016 RECORD # 42094

SAMPLE LOCATION: D17
STATION ID: 395530108312700    LAT.LONG.SEQ.: 395530 1083127 00
DATE OF COLLECTION: BEGIN--750107  END--        TIME--1229
COUNTY CODE: 103   PROJECT IDENTIFICATION: C06400
DATA TYPE: 2  SOURCE: GROUND WATER        GEOLOGIC UNIT: 124GRRV
COMMENTS:
   COLL BY G SAULNIER LOWER AQUIFER SAMPLE FIELD VALUE USED FOR COND
   PH 7.5

ALK.TOT (AS CACO3)       MG/L       582      MAGNESIUM DISS          MG/L       54
ALUMINUM DISSOLVED       UG/L        10      MANGANESE DISSOLVED     UG/L        0
ARSENIC DISSOLVED        UG/L         4      NO2+NO3 AS N DISS       MG/L        0.00
BARIUM DISSOLVED         UG/L       500      PHOS ORTHO DIS AS P     MG/L        0.01
BICARBONATE              MG/L       710      PHOSPHATE DIS ORTHO     MG/L        0.03
BORON DISSOLVED          UG/L      (290)     POTASSIUM DISS          MG/L        1.0
BROMIDE                  MG/L         0.0    RESIDUE DIS CALC SUM MG/L     1090
CALCIUM DISS             MG/L        67      RESIDUE DIS TON/AFT               1.48
CHLORIDE DISS            MG/L        11      SAR                               5.5
CONDUCTIVITY                       1500      SELENIUM DISSOLVED      UG/L        0
DEPTH(FT.FR.SURFACE)                800      SILICA DISSOLVED        MG/L       23
FLUORIDE DISS            MG/L         1.1    SODIUM DISS             MG/L      250
HARDNESS NONCARB         MG/L         0      SODIUM PERCENT                     58
HARDNESS TOTAL           MG/L       390      STRONTIUM DISSOLVED     UG/L     2400
IRON DISSOLVED           UG/L       390      SULFATE DISS            MG/L      330
LEAD DISSOLVED           UG/L         8      WATER TEMP (DEG C)                16.0
LITHIUM DISSOLVED        UG/L        60      ZINC DISSOLVED          UG/L       20

            CATIONS                                       ANIONS

                 (MG/L)         (MEQ/L)                      (MG/L)        (MEQ/L)
CALCIUM DISS      67              3.344  BICARBONATE          710           11.637
MAGNESIUM DISS    54              4.443  CHLORIDE DISS         11            0.311
POTASSIUM DISS     1.0            0.026  FLUORIDE DISS        (1.1)          0.058
SODIUM DISS      250             10.875  SULFATE DISS         330            6.871
                                         NO2+NO3 AS N D         0.00         0.000
                              ---------                                  ---------
                     TOTAL       18.686                          TOTAL      18.876

                 PERCENT DIFFERENCE =    -0.51
```

```
MAIL TO LAKEWOOD COLO
SCHEDULES USED:  364    1    0    0
NUMBER OF DETERMINATIONS: 26
COST OF ANALYSIS $  85.65       DOP--750205
SUBMIT CORRECTIONS TO CENTRAL LAB WITHIN
  15 DAYS FROM BELOW STAMPED DATE. INDICATE
  CENTRAL LAB ID # AND RECORD # WITH RESPONSE.
WRD-QW FILE STORAGE REQUESTED. THE CENTRAL LAB
  ATTEMPTED TO SUPPLY HEADING INFORMATION TO THE
  STATION HEADER FILE. PLEASE CHECK OUR ATTEMPT.
```

GEOLOGICAL SURVEY
TRANSMITTED
FEB 05 1975
SALT LAKE CITY, UTAH
CENTRAL LABORATORY

7500874

OSMIS
LIBRARY CONTROL NO.
6101171401

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Table 41

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                  UNITED STATES DEPARTMENT OF THE INTERIOR
                            GEOLOGICAL SURVEY
                  CENTRAL LABORATORY, SALT LAKE CITY, UTAH

                          WATER QUALITY ANALYSIS
                      LAB ID #  16017 RECORD # 42096

SAMPLE LOCATION: GULF STANDARD CA 3 CI 99 34 ADM
STATION ID: 395524108290302    LAT.LONG.SEQ.: 395524 1082903 02
DATE OF COLLECTION: BEGIN--750108  END--          TIME--1305
COUNTY CODE: 103   PROJECT IDENTIFICATION: C006400
DATA TYPE: 2  SOURCE: GROUND WATER        GEOLOGIC UNIT: 124GRRV
COMMENTS:
   COLL BY G SAVLNIER UPPER AQUIFER SAMPLE FIELD VALUE USED FOR
   PH AND COND

ALK.TOT (AS CACO3)    MG/L     2260      MAGNESIUM DISS         MG/L      17
ALUMINUM DISSOLVED    UG/L       70      MANGANESE DISSOLVED    UG/L       0
ARSENIC DISSOLVED     UG/L        1      NO2+NO3 AS N DISS      MG/L        0.00
BARIUM DISSOLVED      UG/L     1200      PH                                 7.6
BICARBONATE           MG/L     2750      PHOS ORTHO DIS AS P    MG/L        0.08
BORON DISSOLVED       UG/L     7800      PHOSPHATE DIS ORTHO    MG/L        0.25
BROMIDE               MG/L        0.2    POTASSIUM DISS         MG/L        1.0
CALCIUM DISS          MG/L       14      RESIDUE DIS CALC SUM MG/L    2640
CHLORIDE DISS         MG/L       65      RESIDUE DIS TON/AFT                3.59
CONDUCTIVITY                   3600      SAR                              47
DEPTH(FT.FR.SURFACE)            450      SELENIUM DISSOLVED     UG/L       0
FLUORIDE DISS         MG/L       21      SILICA DISSOLVED       MG/L      19
HARDNESS NONCARB      MG/L        0      SODIUM DISS            MG/L    1100
HARDNESS TOTAL        MG/L      110      SODIUM PERCENT                   96
IRON DISSOLVED        UG/L      230      STRONTIUM DISSOLVED    UG/L    2900
LEAD DISSOLVED        UG/L       24      SULFATE DISS           MG/L      34
LITHIUM DISSOLVED     UG/L       80      WATER TEMP (DEG C)               25.0
                                         ZINC DISSOLVED         UG/L      30


             CATIONS                                  ANIONS

                 (MG/L)         (MEQ/L)                      (MG/L)      (MEQ/L)
CALCIUM DISS       14             0.699  BICARBONATE         2750       45.073
MAGNESIUM DISS     17             1.399  CHLORIDE DISS         65        1.834
POTASSIUM DISS      1.0           0.026  FLUORIDE DISS         21        1.106
SODIUM DISS      1100            47.850  SULFATE DISS          34        0.708
                                         NO2+NO3 AS N D         0.00     0.000
                               --------                              --------
                     TOTAL       49.973                    TOTAL       48.719

                   PERCENT DIFFERENCE =     1.27
```

```
MAIL TO LAKEWOOD COLO
SCHEDULES USED:  364     1     0     0
NUMBER OF DETERMINATIONS: 27
COST OF ANALYSIS $  85.65       DOP--750205
SUBMIT CORRECTIONS TO CENTRAL LAB WITHIN
  15 DAYS FROM BELOW STAMPED DATE. INDICATE
  CENTRAL LAB ID # AND RECORD # WITH RESPONSE.
WRO-OW FILE STORAGE REQUESTED. THE CENTRAL LAB
  ATTEMPTED TO SUPPLY HEADING INFORMATION TO THE
  STATION HEADER FILE. PLEASE CHECK OUR ATTEMPT.
```

TRANSMITTED
FEB 05 1975
SALT LAKE CITY, UTAH
CENTRAL LABORATORY

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Table 41 (Cont.)

MAXIMUM AND MINIMUM CONCENTRATIONS OF TRACE ELEMENTS IN SPENT AND FRESH OIL SHALE FROM GULF-STANDARD CORE DRILLING PROGRAM (PPM)

Borehole Number		Cadmium		Antimony		Arsenic		Mercury		Selenium		Fluride Ion		Boron	
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
G-S 1	Fresh	3.45	1.72	0.8	0.2	13.1	4.0	1.92	0.24	0.9	0.2	937	280	516	95
	Spent	3.33	1.46	0.5	0.1	12.3	1.0	1.89	0.19	1.1	0.2	846	64	269	31
G-S 2-3	Fresh	3.98	1.67	1.7	0.2	12.0	0.9	1.54	0.21	0.6	0.1	750	75	190	50
	Spent	2.95	1.56	1.0	0.1	9.8	0.7	1.75	**	0.8	0.1	790	75	150	*
G-S 4-5	Fresh	3.35	1.65	1.0	0.2	12.0	4.7	0.93	0.22	1.3	0.1	1315	152	311	14
	Spent	3.84	1.94	0.7	0.1	8.2	2.6	0.56	0.17	1.1	0.2	1217	79	185	6
G-S 7	Fresh	2.98	1.19	1.1	0.3	8.1	2.5	3.06	0.54	0.8	0.2	1300	140	160	59
	Spent	3.06	1.37	1.2	0.3	7.5	1.1	3.04	0.30	0.9	0.2	1100	140	140	37
G-S 9	Fresh	3.43	1.60	1.0	0.2	12.4	4.9	1.23	0.21	0.4	0.1	994	188	243	81
	Spent	3.87	1.85	0.6	0.1	15.7	1.5	1.25	0.05	0.5	0.1	779	84	329	5
G-S 10	Fresh	4.32	1.33	1.1	0.2	11.4	4.0	1.18	0.18	0.7	0.1	1068	178	242	39
	Spent	3.17	2.16	0.9	0.2	7.4	2.8	0.48	0.13	0.9	0.1	836	155	215	30
G-S 11	Fresh	3.12	0.84	1.2	0.1	11.4	4.2	1.65	0.13	0.9	0.1	968	131	344	88
	Spent	3.13	1.59	0.8	0.1	8.9	3.0	0.42	0.12	1.2	0.1	771	215	240	38
G-S 15	Fresh	3.56	1.31	1.3	0.2	15.1	2.2	1.17	0.11	1.0	0.1	1488	366	267	19
	Spent	3.37	1.35	1.2	0.1	12.4	1.0	0.72	0.08	1.0	0.3	1013	155	211	31

*Less than 0.3
**Less than 0.01

Table 42

OIL AND GAS WELLS
COREHOLES, MONITORING WELLS AND WATER WELLS
WITHIN C-b TRACT AND AREA OF INTEREST

PAGE 2

WELL NAME AND NUMBER	LOCATION	T.D.	DEEPEST FORMATION PENETRATED	PRODUCING FORMATION	CURRENT STATUS	COMPANY NAME
	T3S R97W					
33X-1	NW SE Sec. 1	2078	Green River	None	Corehole	Oxy
Cb-1	SW SW Sec. 1	2106	Green River	None	Corehole	Oxy
SG-1	NW SE Sec. 2	2525	Green River	None	Corehole	Oxy
SG-1A	NW SE Sec. 2	1180	Green River	None	Corehole	Oxy
A-3	SW SE Sec. 2	112	Uinta	None	Alluvial Monitor	Oxy
J.M. Greeno #1	NE NE Sec. 4	<2500	Wasatch (objective)	None	Corehple-capped	Shell
J.M. Greeno #2	NE NE Sec. 4	<2500	Wasatch (objective)	None	Corehole-capped	Shell
J.M. Greeno #3	NE NE Sec. 4	<2500	Wasatch (objective)	None	Corehole-capped	Shell
J.M. Greeno #4	NE NE Sec. 4	<2500	Wasatch (objective)	None	Corehole-capped	Shell
SG-9	SE SE Sec. 11	2750	Green River	None	Corehole	Oxy
HQ-4	SE NE Sec. 11	1552	Green River	None	Corehole	Oxy
32X-12	SW NE Sec. 12	2191	Green River	None	Corehole	Oxy
A-4	SW NE Sec. 13	64	Uinta	None	D & A	Oxy
SG-10	NE NE Sec. 13	2211	Green River	None	Corehole	Oxy
SG-10A	NE NE Sec. 13	1300	Green River	None	Corehole	Oxy
SG-21	SW SE Sec. 13	1036	Green River	None	Corehole	Oxy
TG 71-1	NE NW Sec. 13	2530	Green River	None	Corehole	Tosco

Ref.: Application for a permit to inject water produced from Oil Shale Tract C-b, Rio Blanco County, Colorado, February. Section 2

(Cb Shale Oil Project, 1979, Development Monitoring Program for Tract Cb.)

Table 43

OIL AND GAS WELLS
COREHOLES, MONITORING WELLS AND WATER WELLS
WITHIN C-b TRACT AND AREA OF INTEREST

WELL NAME AND NUMBER	LOCATION	T.D.	DEEPEST FORMATION PENETRATED	PRODUCING FORMATION	CURRENT STATUS	COMPANY NAME
	T3S R97W Con't.					
Rio Blanco U-2 Govt	NE SW Sec. 21	8470	N.D.	N.D.	Suspended Operation	CER Geonuclear
Scandard Draw #2	SE NW Sec. 21	3600	N.D.	N.D.	Suspended Operation	Equity Oil
Scandard Draw #1	NE NE SE Sec. 22	9850	Mesa Verde	Mesa Verde	Gas Well (Shut In)	Equity Oil
SG-18	SE SE Sec. 25	1430	Green River	None	P & A	Oxy
SG-18A	SE SE Sec. 25	1330	Green River	None	Corehole	Oxy
Megor #4	SW SW NE Sec. 27	7111	Ft. Union	None	Dry Hole (P & A)	Equity Oil
Carter Upper Willow #2A	NW NE Sec. 27	2247	Green River	None	Corehole	Carter
Scandard Draw #3	SE NW Sec. 28	8656	Mesa Verde	None	D & A	Equity Oil
	T3S R96W					
A-7	NW NW Sec. 5	51	Uinta	None	Alluvial Monitor	Oxy
A-8	SE NE Sec. 5	70	Uinta	None	Alluvial Monitor	Oxy
SG-19	NW NW Sec. 5	981	Green River	None	Corehole	Oxy
Cb-3	NW SW SE Sec. 5	2123	Green River	None	Corehole	Oxy
Cb-2	NW SE Sec. 6	1482	Green River	None	Corehole	Oxy
Cb-2b	SW SE Sec. 6	1280	Parachute Creek	None	P & A	Oxy
Oldland 015500 A	NE NE Sec. 7	800	N.D.	N.D.	Water well, 180 (gpm)	Oldland Bros.
SG-6	NE SW Sec. 7	2220	Green River	None	Corehole	Oxy
SG-11	SE SE Sec. 7	2826	Green River	None	Corehole	Oxy

Ref.: Application for a permit to inject water produced from Oil Shale Tract C-b, Rio Blanco County, Colorado, February. Section 2

Table 43 (cont.)

OIL AND GAS WELLS
COREHOLES, MONITORING WELLS AND WATER WELLS
WITHIN C-b TRACT AND AREA OF INTEREST

WELL NAME AND NUMBER	LOCATION	T.D.	DEEPEST FORMATION PENETRATED	PRODUCING FORMATION	CURRENT STATUS	COMPANY NAME
	T3S R96W Con't.					
AT-1	NE SW Sec. 7	1700	Green River	None	Aquifer Test Well	Oxy
AT-1A	NE SW Sec. 7	1620	Green River	None	Aquifer Test Well	Oxy
AT-1A1	NE SW Sec. 7	1300	Green River	None	Aquifer Test Well	Oxy
AT-1B	NE SW Sec. 7	1638	Green River	None	Aquifer Test Well	Oxy
AT-1C	NE SW Sec. 7	1646	Green River	None	Aquifer Test Well	Oxy
AT-1D	NE SW Sec. 7	1640	Green River	None	Aquifer Test Well	Oxy
MQ-22	NE SW Sec. 7	1843	Green River	None	Corehole	Oxy
14X-7	NE SW Sec. 7	962	Green River	None	Corehole	Oxy
MQ-7	SE SW Sec. 8	1740	Green River	None	Corehole	Oxy
A-11	SE NE Sec. 8	66	Uinta	None	Alluvial Monitor	Oxy
A-9	NW SE Sec. 9	57	Uinta	None	Alluvial Monitor	Oxy
SG-8	NE SW Sec. 9	2608	Green River	None	Corehole	Oxy
Federal 28	NW SE Sec. 10	3100	Green River	None	Corehole	Arco
So Piceance #8	NW NE Sec. 10	3107	Green River	None	Dry Hole (P & A)	Equity Oil
Oldland #3	NE NE Sec. 10	2395	Green River	--	Converted to Water Well by Tpsco, 225 gpm	Equity Oil (driller)
Oldland #1	NW NE Sec. 11	2461	Wasatch	Douglas Creek	Abandoned Producer (P & A)	Equity Oil

Ref.: Application for a permit to inject water produced from Oil Shale Tract C-b, Rio Blanco County, Colorado, February. Section 2

Table 43 (cont.)

Table 43 (cont.)

OIL AND GAS WELLS
COREHOLES, MONITORING WELLS AND WATER WELLS
WITHIN C-b TRACT AND AREA OF INTEREST

WELL NAME AND NUMBER	LOCATION	T.D.	DEEPEST FORMATION PENETRATED	PRODUCING FORMATION	CURRENT STATUS	COMPANY NAME
	T3S R96 W Con't.					
SG-17	SW SW Sec. 16	2460	Green River	None	Corehole	Oxy
A-10	SE NW Sec. 16	67	Uinta	None	Alluvial Monitor	Oxy
TG-71-2	NE NE Sec. 17	1162	Green River	None	Corehole	Oxy
A-12	SW SE Sec. 17	14	Uinta	None	Alluvial Monitor	Oxy
Cb-4	NW SW Sec. 17	1470	Green River	None	Corehole	Oxy
NQ-12D	NW SE Sec. 18	1670	Green River	None	Corehole	Oxy
A-13	NW SE Sec. 18	14	Uinta	None	Alluvial Monitor	Oxy
TG 2-1	NE NE SW Sec. 21	2400	Green River	None	Corehole	Tosco
Oldland 000777N	SW SW Sec. 23	300	N.D.	N.D.	Water well, 10 (gpm)	Oldland Bros.
Govt #7	NW SE Sec. 23	3024	Green River	None	Dry Hole (P & A)	Equity Oil
TG 2-3	SW SW Sec. 23	1131	N.D.	None	Corehole	Tosco
Oldland #2	SW SW Sec. 26	3008	Green River	None	Dry Hole (P & A)	Equity Oil
TG 71-3	NE NW Sec. 29	N.D.	N.D.	None	Corehole	Tosco

Ref.: Application for a permit to inject water produced from Oil Shale Tract C-b, Rio Blanco County, Colorado, February. Section 2

V. Water (cont'd)

Upper Aquifer Wells

Before Recompletions		After Recompletions	
Station	Code	Station	Code
CB-2	WX02		
CB-4	WX04		
SG-10A	WX10	SG-10A-1	WE10
SG-1A	WX11	SG-10A-2	WD10
SG-1-2	WX12		
SG-17-2	WX17		
SG-18A	WX18		
SG-19	WX19		
SG-20	WX20		
SG-21	WX21		
AT-1C-3	WX44		
SG-11-3	WX55		
SG-6-3	WX63		
SG-8-2	WX82		
SG-9-2	WX92		
32X-12	WX32		
33X-1	WX33		
41X-1	WX41		
TH75-5A	WX64		
TH75-13A	WX65		
TH75-18A	WX67		
TH75-9A	WX69		
CER RB-D-02	WX71		
TH75-15A	WX72		
UNION 8-1	WX73		
COLONY 12-596	WX74		
TH-5	WX75		

Lower Aquifer Wells

Before Recompletions		After Recompletions	
Station	Code	Station	Code
CB-1	WY01		
CB-3	WY03		
SG-10	WY09	SG-10R	WG10
SG-1-1	WY12		
SG-17-1	WY18	SG-17-1R	WY17
AT-1C-1	WY45		
AT-1C-2	WY46		
SG-11-1	WY51	SG-11-1R	WY52
SG-11-2	WY54		
SG-6-1	WY61		
SG-6-2	WY62		
SG-8	WY80	SG-8R	WY81
SG-9-1	WY91		
AT-1	WY44		
TH75-5B	WY64		
TH75-13B	WY65		
EQUITY-1	WY66		
TH75-13B	WY67		
TH75-10B	WY68		
TH75-9B	WY69		
EQUITY-SULFUR-1A	WY70		
CER RB-D-03	WY71		
TH75-15B	WY72		
TG71-3	WY75		
TG71-5	WY76		
GETTY 9-40	WY77		
TG71-4	WY78		
EQUITY BS-13	WY79		

(Cb Shale Oil Project, 1979, Development Monitoring Program for Tract Cb.)

Table 43 (cont.)

(Cb Shale Oil Venture,1975, Environmental Baseline Program Annual Summary 1.)

WELL SUMMARY TABLE

1. Well Designation	SG-17	SG-18	SG-18a	SG-19	SG-20	SG-21	Cb-1	Cb-2	Cb-2b	Cb-3	Cb-4	NO7B	NO12D	NO 4	NO22
2. Well Type	CH	AB (GHT)	GHT	CH GHT	GHT	GHT	GHT	GHT	AB (GHT)	GHT	GHT	CH	CH	CH	CH
3. Completion Date	1/13/75	10/13/74	10/18/74	9/28/74	12/13/74	1/8/75	#	#	9/20/74	#	#				
4. Total Depth (Geolograph)	2460	1430	1330	980	987	1036	2104	1482	1220	2122	1470	1740	1670	1554	1541
5. Water Data							#	#		#	#	----None----			
a. Drilling Water Production	C2Q	C1Q	C1Q	C1Q	C2Q	C2Q			C1Q						
b. Drilling Water Samples	31	3	1	4	5	5									
c. Water Quality Analyses	C2Q 3Q	C1Q	C1Q	C1Q	C2Q	C2Q									
6. Aquifer Data							#	#		#	#	-----None-----			
a. Drill Stem Tests	C2Q 3Q				C2Q 3Q	C2Q 3Q									
b. Jetting Tests	C2Q 3Q	C1Q	C1Q	C1Q	C2Q	C2Q									
7. Geophysical Logs, Electric							F	F		F	F				
a. Schlumberger (1) Borehole, Compensated Sonic	C2Q	C1Q		C1Q	C2Q	C2Q						*		*	*
(2) Laterolog	C2Q	C1Q		C1Q		C2Q						*	*	*	*
(3) Formation Density	C2Q	C1Q		C1Q	C2Q	C2Q						*	*	*	*
(4) Compensated Neutron Formation Density												*	*	*	*
(5) Temperature	C2Q	C1Q		C1Q	C2Q	C2Q	C2Q	C2Q		C2Q	C2Q	*	*	*	*
(6) Cement Bond Log	C3Q						C3Q	C3Q			C3Q				
(7) Perforated Depth Control	C3Q						C3Q	C3Q							
(8) Casing Collar Log and Perforating Record							C3Q	C3Q			C3Q				
(9) Oriented Perforating Record and Casing Collar Log	C3Q														
b. Geophysical Logs, Other															
(1) Birdwell, Caliper log												*	*	*	*
(2) McCullough, Temperature															
8. Field Lithologic Log	C3Q	C3Q	C1Q	C3Q	C2Q	C2Q	F	F	C1Q	F	F				
9. Cored Interval							#	#		#	#				
a. Top	800	1380	NA	930					NA			70	70	70	70
b. Bottom	2460	1426	NA	980								TD	TD	TD	TD
10. Assay Data							#	#	NA	#	#				
a. Fischer Assay	C3Q	C3Q		C1Q	C3Q	C3Q	F	F		F	F				
b. Soluble Sodium	C3Q	C3Q		C3Q	C3Q	C3Q									
c. Alumina	C3Q	C3Q		C3Q	C3Q	C3Q									
11. Trace Element Analysis							#	#	NA	#	#				
12. Rock Mechanics Data							RQD #	RQD #	NA	RQD #	RQD #				
13. Gas Data							#	#		#	#				
a. Drilling Log	C2Q	C1Q	C1Q	C1Q	C2Q				C1Q						
b. Bomb Samples	31	1	1	4	5	4			1			5	4	4	4
c. Bomb Analyses	C1Q-C3Q	C1Q	C1Q	C1Q	C2Q	C2Q			C1Q			C4Q	C4Q	C4Q	C4Q
14. Completion Data	C2Q	C1Q	C1Q	C1Q	C2Q	C2Q	C1Q	C2Q	C1Q	C1Q	C1Q	C4Q	C4Q	C4Q	C4Q
15. Survey Plat	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q	C3Q	C3Q	C4Q	C4Q

KEY:
NA = Not Applicable
Inc. = Incomplete
C1Q = Complete, First Quarterly Report
C2Q = Complete, Second Quarterly Report
C3Q = Complete, Third Quarterly Report

AT = Aquifer Test
CH = Core Hole
GHT = Groundwater Test Hole

*Birdwell Company logs run on this well instead of Schlumberger. Logs in Quarterly Report #4.
**Alluvial Pump Test.
Not applicable. Wells drilled prior to granting C-b Tract Lease.

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Table 44

WELL SUMMARY TABLE

1. Well Designation	AT-1	AT-1a	AT-1a	AT-1b	AT-1d	[illegible]	SG-1	SG1a	SG-6	SG-8	SG-9	SG-10	SG-10a	SG-11
2. Well Type	AT	AT (CH)	AT	AT	AT	AT	CH	GHT	CH (AT)	CH	CH	CH (AT)	GHT	CH (AT)
3. Completion Date	1/23/75	7/17/74	7/10/74	7/20/74	8/13/74	[illegible]/74	12/5/74	2/7/75	8/22/74	11/27/74	10/23/74	6/29/74	7/10/74	9/8/74
4. Total Depth (Geolograph) (feet)	1700	1621	1341	1638	1640	1640	2525	1180	2220	2608	2750	2211	1333	2826
5. Water Data														
a. Drilling Water Production	C1Q 2Q	C1Q	C1Q	C1Q	C1Q	C1Q	C2Q	C2Q	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q
b. Drilling Water Samples (# taken)	1	4	NA	NA	4	NA	7	NA	5	7	5	4	NA	25
c. Water Quality Analyses	C1Q 2Q	C1Q			C1Q		C2Q		C1Q	C2Q	C1Q	C1Q		C1Q
6. Aquifer Data														
a. Drill Stem Tests		C1Q			C1Q		C2Q C3Q			C3Q		C1Q		
b. Jetting Tests	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q	C2Q	C3Q	C1Q		C1Q	C1Q	C1Q	C1Q
7. Geophysical Logs,														
a. Schlumberger (1) Borehole, Compensated Sonic	C1Q	*		C1Q	C3Q	C1Q	C2Q		C3Q	C2Q	C2Q	*		C1Q
(2) Laterolog	C1Q	*		C1Q	C3Q	C1Q	C2Q		C3Q	C2Q	C2Q	*		C1Q
(3) Formation Density	C1Q	*		C1Q		C1Q	C2Q	C2Q		C2Q	C2Q	*		
(4) Compensated Neutron Formation Density		*		C1Q	C3Q	C1Q			C3Q			*		
(5) Temperature	C1Q	C1Q		C1Q	C3Q	C1Q	C2Q		C3Q	C2Q	C2Q	C1Q		C1Q
(6) Cement Bond Log		*		C3Q	C3Q	C3Q	C3Q		C3Q		C3Q	*		C3Q
(7) Perforated Depth Control							C3Q				C3Q			
(8) Casing Collar Log and Perforating Record														
(9) Oriented Perforating Record and Casing Collar Log				C3Q	C3Q	C3Q	C3Q		C3Q		C3Q			C3Q
b. Geophysical Logs, Other														
(1) Welex, Micro-seismogram		C1Q										C1Q		
(2) McCullough, Temperature				C1Q										
8. Field Lithologic Log	C1Q	C3Q	C1Q	C1Q	C1Q	C1Q	C3Q	C2Q	C3Q	C3Q	C3Q	C3Q	C1Q	C3Q
9. Cored Interval (feet from surface)														
a. Top	NA	1270	NA	NA	NA	NA	550	NA	1195	580	1200	1200	NA	750
b. Bottom	NA	1519	NA	NA	NA	NA	2525	NA	2220	2608	2750	2211	NA	2810
10. Assay Data														
a. Fischer Assay	NA	C1Q	NA	NA	NA	NA	C3Q	NA	C3Q	C3Q	C2Q	C1Q	NA	C3Q
b. Soluble Sodium	NA	C1Q	NA	NA	NA	NA	C3Q	NA	C3Q	C3Q	C2Q	C1Q	NA	C3Q
c. Alumina	NA	C1Q	NA	NA	NA	NA	C3Q	NA	C3Q	C3Q	C2Q	C1Q	NA	C3Q
11. Trace Element Analysis			C2Q 3Q							C2Q 3Q	C2Q 3Q	C2Q 3Q		
12. Rock Mechanics Data		C1Q										C1Q		
13. Gas Data														
a. Drilling Log	NA	NA	NA	NA		NA	C1Q		C1Q	C1Q	C1Q		NA	C1Q
b. Bomb Samples (# taken)	NA	NA	NA	NA	2	NA	9		4	11	8		NA	6
c. Bomb Analyses	C3Q	NA	NA	NA	C2Q	NA	C1Q 2Q		C1Q	C1Q 2Q	C1Q			C3Q C1Q
14. Completion Data	C2Q	C1Q	C1Q	C1Q	C1Q	C1Q	C3Q	C2Q	C1Q	C2Q	C1Q	C1Q	C1Q	C1Q
15. Survey Plat	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q	C3Q	C1Q	C1Q	C1Q	C1Q	C1Q	C1Q

KEY:
NA • Not Applicable
Inc. • Incomplete
C1Q • Complete, First Quarterly Report
C2Q • Complete, Second Quarterly Report
C3Q • Complete, Third Quarterly Report

AT • Aquifer Test
CH • Core Hole
GHT • Groundwater Test Hole

*Birdwell Company logs run on this well instead of Schlumberger. See Quarterly Report #1.
**Alluvial Pump Test.
Not applicable. Wells drilled prior to granting C-b Tract Lease.

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Table 44(cont.)

UPPER TRACT AQUIFER WELLS SAMPLING TIME INTERVALS FOR LEVELS AND WATER QUALITY

(Cb Shale Oil Project, 1980, Annual Reports.)

STATION I.D.	COMPUTER CODE	SAMPLE TYPE	FIRST SAMPLE DATE	1974	1975	1976	1977	1978	1979
UPPER AQUIFER		LEVEL							
CB-2	WX02	"	OCT 1974						
CB-4	WX04	"	OCT 1974						
SG-10A	WX10	"	JUN 1975						
SG-1A	WX11	"	FEB 1979						
SG-1-2	WX12	"	JUN 1975						
SG-17-2	WX17	"	JUN 1975						
SG-18A	WX18	"	NOV 1974						
SG-19	WX19	"	JUL 1975						
SG-20	WX20	"	JUN 1975						
SG-21	WX21	"	JUN 1975						
AT-1C-3	WX44	"	OCT 1974						
SG-11-3	WX55	"	OCT 1974						
SG-6-3	WX63	"	JUN 1975						
SG-8-2	WX82	"							
SG-9-2	WX92	"	NOV 1974						
32X-12	WX32	"	JUL 1977						
33X-1	WX33	"	JUL 1977						
41X-1	WX41	"	OCT 1979						
TH75-5A	WX64	"	AUG 1979						
TH75-13A	WX65	"	AUG 1979						
TH75-18A	WX67	"	AUG 1979						
TH75-9A	WX69	"	AUG 1979						
CER RB-D-02	WX71	"	AUG 1979						
TH75-15A	WX72	"	AUG 1979						
UNION 8-1	WX73	"	SEP 1979						
TH-5	WX75	"	SEP 1979						
SG-10A-1	WE10	"	NOV 1979						
SG-10A-2	WD10	"	NOV 1979						
		QUALITY							
CB-2	WX02	"	NOV 1974						
CB-4	WX04	"	NOV 1974						
SG-10A	WX10	"	APR 1975						
SG-1A	WX11	"							
SG-1-2	WX12	"	APR 1975						
SG-17-2	WX17	"	APR 1975						
SG-18A	WX18	"	NOV 1974						
SG-19	WX19	"	NOV 1974						
SG-20	WX20	"	APR 1975						
SG-21	WX21	"	APR 1975						
32X-12	WX32	"							
33X-1	WX33	"							
AT-1C-3	WX44	"	NOV 1974						
SG-11-3	WX55	"	APR 1975						
SG-6-3	WX63	"	APR 1975						
SG-8-2	WX82	"	APR 1975						
SG-9-2	WX92	"	NOV 1974						

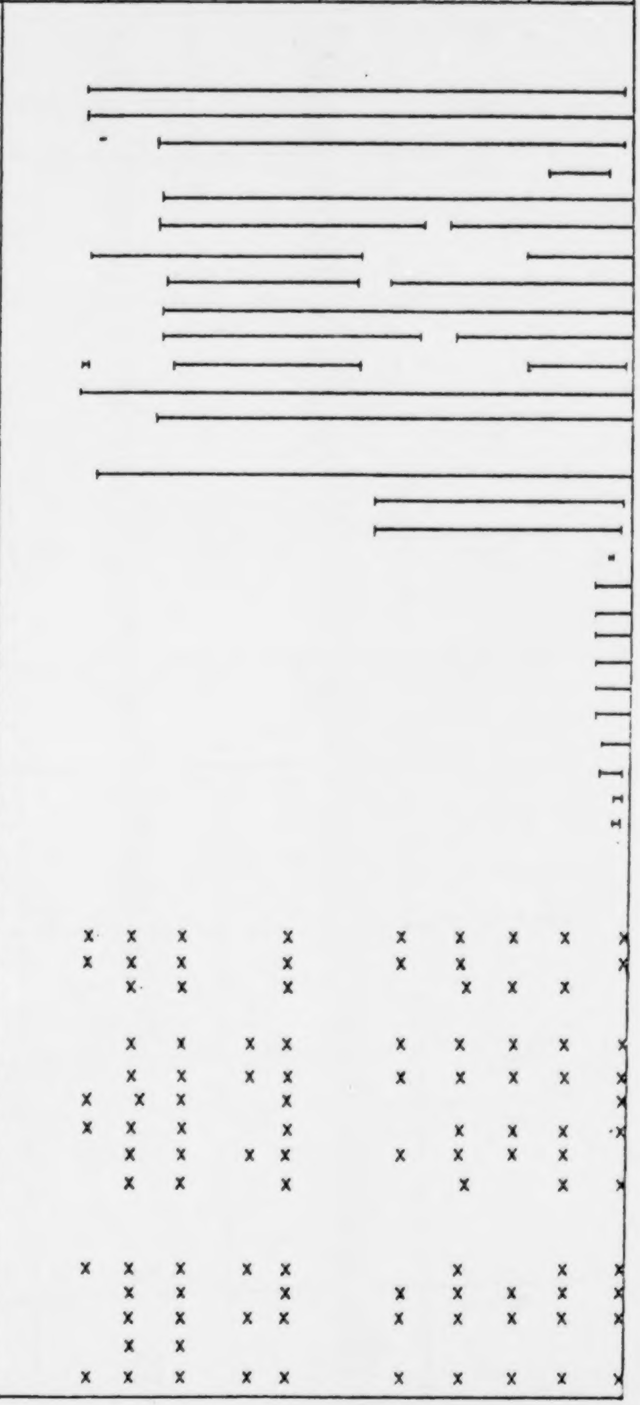

Table 45

WELL DATA FROM JET TESTING

Well No.	Depth of Test	Transmissivity ft^2/day	Conductivity Micromhos	Production gal/min.
Cb-1	1280	134	1820	178
	1480	167	2000	-
	2100	195	3000	386
Cb-2	1280	668	2600	328
	1480	1203	2400	326
Cb-3	1240	869	2460	250
	1450	989	2400	300
	2122	1176	3040	350
Cb-4	1250	58.8	870	100
	1468	321	1010	230
SG-1	600	762	1000	610
	700	709	950	565
	1040	634	1000	467
	1105	820	1000	673
	2220	1158	2000	794
	2525	989	1900	840
SG-6	845	21.4	850	18
	1320	251	1250	189
	1440	330	1250	211
	1520	368	1300	211
	2220	439	1400	224
SG-8	600	334	1600	72
	970	540	1620	251
	1000	805	1600	251
	2115	1114	2400	494
	2608	1350	2600	458
SG-9	990	30.7	850	54
	1285	136	1200	282
	1360	179	1200	260
	2540	386	1100	274
	2750	310	1050	202
SG-10	960	23.5	-	21
	1330	398	850	148
	1430	402	900	167
	2211	1013	2100	152
SG-11	810	134	1180	112
	860	118	950	108
	1330	685	1005	176
	1390	566	1050	-
	1490	316	1200	108
	2465	752	2050	234
	2826	802	2250	148
SG-17	830	28.9	800	27
	1250	256	1400	103
	1330	284	-	153
	1622	271	1200	134
	2460	118	4400	162
SG-21	960	1.34	1100	11
	1036	660	600	292
TG-71-1	700	294	1140	200
	1040	802	9250	860
	2080	-	3300	-
	2150	-	1480	-
	2250	-	2800	-
	2300	-	3980	-
	2400	-	2500	-
	2530	450	2740	260
TG-71-2	630	-	760	-
	720	-	1100	-
	1000	628	-	-
	1162	615	-	-

(Cb Shale Oil Venture, 1976, Environmental Baseline Program, Volume II, Final Report, Hydrology.) Table 46

SUMMARY OF DRILL STEM TEST INTERPRETATIONS ECA, 1978

	INTERVAL TESTED (FT)	STEM LENGTH (FT)	PERMEABILITY (MD)		TRANSMISSIVITY (GPD/FT)	ZONE TESTED
	WELL SG-17			ECA		
1	386-436	50	Did Not Analyze			
2	788-808	20	Data Scattered			
3	822-869	47	10	11.0	8.8	
4	866-919	53	26	12.7	26	
5	919-970	51	0.83	34.0	0.76	
6	967-1017	50	17	10.7	15	Four Senators
7	1017-1067	50	78	19.9	71	
8	1066-1116	50	23	20.0	21	
9	1116-1166	50	33	8.0	30	
10	1164-1212	48	127	185.0	110	
11	1200-1224	24	32	21.2	14	A Groove
12	1215-1224	9	25	20.8	4.1	A Groove
13	1224-1250	26	34	3.00	16	
14	1251-1280	29	3.5	8.0	1.8	
15	1280-1309	29	25	13.0	13	
16	1308-1336	28	Data Scattered			
17	1327-1374	47	45	52	39	
18	1373-1419	46	220	15	180	Lower Mahogany-B Groove
19	1423-1470	47	Test Failed			
20	1423-1470	47	6.4	23.9	5.5	
21	1473-1522	49	1.2	3.0	1.1	
22	1428-1522	94	1.2	4.7	2.1	
23	1514-1572	58	2.8	4.0	3.0	
24	1561-1622	61	1.9	23.0	2.1	
25	1618-1670	52	1.7	4.0	1.6	L-5
26	1668-1720	52	6.7	30.0	6.3	L-5
27	1711-1770	59	5.3	6.0	5.7	
28	1768-1820	52	5.7	42.0	5.4	
29	1818-1870	52	2.3	2.0	2.2	
30	1869-1920	51	230	275	210	Base R-5 - Top L-4
31	1918-1970	52	2.0	4.0	1.9	L-4
32	1968-2020	52	0.95	169	0.89	Base L-4 - Top R-4
33	2018-2070	52	1.7	—	1.6	
34	2120-2170	50	8.2	30	7.4	Base L-3 - Top R-3
35	2220-2270	50	0.43	—	0.39	
36A	2320-2370	50	Data Scattered			
36B	2315-2370	55	1.5	—	1.5	
37	2395-2460	65	38	35	45	
	WELL SG-20					
1	896-945	49	Data ~~In~~sufficient			A Groove
2	945-986	41	4.3	—	3.2	Upper Mahogany
	WELL SG-21					
1	1000-1036	36	3.9	20	2.5	Upper Mahogany
2	950-1000	50	30	—	27	A Groove

Table 47

SUMMARY OF MINI PUMP TESTS

BOREHOLES SG - 1/SG - 1A

Min. Test No.	Borehole SG - 1 Depth of Packers (Ft.) Upper	Borehole SG - 1 Depth of Packers (Ft.) Lower	Borehole Depth (Ft.)	Borehole SG - 1A Depth of Packers (Ft.) Upper	Borehole SG - 1A Depth of Packers (Ft.) Lower	Borehole Depth (Ft.)	Production Zone	Comments
1	907	944	2525	-	-	900	Above rich Zone 1	
2	944	968	2525	-	-	938	Above rich Zone 2	
3	907	944	2525	-	-	938	Above rich Zone 2	Packer leakage repeated as Min 4
4	907	944	2525	-	909	938	Between rich Zones 1 and 2	
5	944	968	2525	-	947	969	Between rich Zones 2 and 3	Packer leakage repeated as Min 6
6	944	968	2525	-	947	969	Between rich Zones 2 and 3	
7	968	1000	2525	-	968	1001	Between rich Zones 3 and 4	
8	1123	1188	2525	-	1125	1180	Between rich Zones 5 and 6	
9	969	1001	2525	968	1002	1180	Between rich Zones 3 and 4	Packer malfunction repeated as Min 10
10	968	1008	2525	969	1009	1180	Between rich Zones 3 and 4	

NOTES

1. Jetting conducted in SG - 1A from within the production zone indicated; pressure response in the production zone, above and below it, measured in Borehole SG - 1, 100 ft. distant.

2. "Rich Zones" are located at the following depths in the boreholes:

Rich Zone	Depth (Ft.)
1	907
2	944
3	968
4	1008
5	1123
6	1180

(Cb Shale Oil Venture, 1975, Summary Quarterly Reports #1 through #9.)

Table 48

ROCK PROPERTIES FOR THEORETICAL MINI-PUMP CALCULATIONS

Layer No.	Permeability, md.		Porosity %	Layer Thickness, ft.
	Horizontal	Vertical		
1	10000.	10000.	1000.	2.
2	20.	10.	20.	410.
3	100.	50.	20.	100.
4	100.	50.	20.	450.
5	100.	50.	20.	10.
Tight Zone → 6	*	*	0.1	**
7	100.	50.	20.	10.
8	100.	50.	20.	50.
9	100.	50.	20.	100.
10	100.	50.	20.	450.

* Varied from 0.01 to 5.0 md.

** Used values of 3.0 and 5.0 feet

(ibid.)

Table 49

Table 50

RESULTS OF MINI PUMP TESTS
ON SG 1 AND SG 1A (ECA INTERPRETATION)

TEST	INTERVAL	T(gpd/ft)	K_h (md)	S	L (day^{-1})	K_h (md)	b'(ft)**
MPT-4	907-944	200 (12.8)*	264 (16.9)	8×10^{-5} (2×10^{-4})	< 3X10-5 (1.1×10^{-4})	< 0.2 (10-3)	5
MPT-6	944-968	? (39.4)	? (90)	10^{-5} (9×10^{-4})	10^{-4} (7.5×10^{-4})	? (.2)	6
MPT-8	1125-1181	200 (138)	196 (135)	2×10^{-5} (4×10^{-4})	<10-5 (1.8x10-5)	< .02 (1.2×10^{-4})	6
MPT-10	968-1008	50 (86.5)	69 (119)	3×10^{-5} (1.2x10-3)	10-4 (10-3)	? (.01)	6

* Numbers in parentheses are those calculated by Lessee at Tract C-b.

** Estimated Aquitard Thickness from Quarterly Report No. 4, V. 1, pp. IIB-107 through IIB-114.

(Cb Shale Oil Project, 1978 and 1979, Reinjection Application Permit, prepared by ECA Associates.)

AQUIFER TEST OBSERVATION WELL DATA

WELL NO.	DISTANCE (FEET) -FROM AT-1	ZONES MONITORED
AT-1	-	Upper Aquifer
AT-1a	79 feet	Lower Aquifer Mining Zone
AT-1a1	85 feet	Upper Aquifer
AT-1b	102 feet	Upper Aquifer
AT-1c	102 feet	Upper Aquifer Mahogany Vugular Lower Aquifer
AT-1d	127 feet	Upper Aquifer Mahogany Vugular
SG-6	1289 feet	Upper Aquifer Mahogany Vugular Lower Aquifer
SG-10	2339 feet	Lower Aquifer Mahogany Vugular
SG-10a	2350 feet	Upper Aquifer
SG-11	3236 feet	Upper Aquifer Mahogany Vugular Lower Aquifer

Mahogany Vugular is the interval between the base of the Mining Zone and the B groove.

(Cb Shale Oil Venture, 1975, Summary Quarterly Reports #1 through #9.)

Table 51

RESULTS OF UPPER MAIN AQUIFER PUMP TEST
(ECA INTERPRETATION)

Thickness tested - 713 ft.

WELL	T (gpd/ft)	S
AT 1	1184	----
AT 1A	1183 (1144)☆	9.1×10^{-4} (4.2×10^{-4})
AT 1B	1218 (1212)	9.2×10^{-4} (3.7×10^{-4})
AT 1C	1123 (957)	4.9×10^{-4} (2.7×10^{-4})
AT 1D	1059 (972)	7.3×10^{-4} (3.0×10^{-4})
+SG 6	1444 (1586)	1.6×10^{-3} (1.7×10^{-3})
+SG 10A	1645 (1743)	4.2×10^{-4} (4.2×10^{-4})
+SG 11	1081 (1159)	8.7×10^{-5} (6.9×10^{-5})

☆ Numbers in parentheses are those calculated by Lessee from Tract C-b.

+ The data from these wells is of much lower quality than that from the five wells on the aquifer test pad.

(Cb Shale Oil Project, 1978 and 1979, Reinjection Permit, prepared by ECA Associates.)

Table 52

RESULTS OF LOWER MAIN AQUIFER PUMP TEST
(ECA INTERPRETATION)

Thickness tested - 270 ft.

WELL	T(gpd/ft)	S
AT 1A	362 (328)*	3.1×10^{-4} (4.2×10^{-4})
AT 1C (String #1)+	---- (153)	------- (1.2×10^{-4})
AT 1C (String #2)+	--- (306)	------- (1.2×10^{-5})
AT 1D	324 (265)	? (2.7×10^{-5})
SG6 (String#1)+	--- (689)	------- (5.3×10^{-4})
SG6 (String #2)+	--- (267)	------- (6.5×10^{-5})
SG10+	--- (110)	------- (3.9×10^{-5})

* Numbers in parentheses are those calculated by Lessee of Tract C-b.

+ Graphs by Lessee sufficiently questionable as to prevent interpretation without original data.

(ibid.)

Table 53

Aquifer Definition
Cb Tract Well 32X-12

Aq. no.	Top of Aquifer[1] (ft)	Thickness[1] (ft)	Est. Transmissivity[1] (GPD/ft)	Equilibrium Pressure[2] (psi)	TDS[3] (mg/l)	Fluoride[3] (mg/l)	Boron[4] (mg/l)	Est. Max. Inst. Surge[5] (GPM)	Horiz. Perm. KMd
1	740	145	40	179	1050[4]	0.1[4]	0.08[4]	45	15
2	900	30	40	223	1050[4]	0.1[4]	0.08[4]	57	75
3	944	76	40	252	1050[4]	0.1[4]	0.08[4]	64	30
4	1094	26	62	306	540	12	1.2	120	130
5	1135	10	295	320	540	12	1.2	599	1600
6	1150	16	115	328	750	16	1.4	239	400
7	1222	25	330	361	704	16	1.4	756	725
8	1290	14	65	388	995	10	0.3	160	260
9	1393	57	265	442	645	19	1.0	743	260
10	1475	20	68	470	645	19	1.0	203	190
11	1506	14	53	482	581	17	1.0	162	210
12	1580	13	67	514	610	20	0.3	218	280
13	1632	21	32	538	720	20	0.2	109	85
14	1748	22	40	588	1400	24	1.1	149	100
15	1867	33	44	642	595	8.9	0.9	179	75
16	1975	25	63	687	1480	20	1.8	275	140
17	2016	24	240	705	1480	20	1.8	1073	550
18	2056	10	150	719	2500	45	0.9	684	825

1) As shown by the Pump/Spinner test of 5-4-77; all depths are measured from the kelly bushing

2) Computed from hydrostatic gradient to the midpoint of the aquifer from a static water level at 400 ft.

3) Based on stratigraphic correlation to the water samples taken during the drill-stem tests on SG-17

4) Based on the Uinta water sample from 33X-1

5) Computed at one-hour of drawdown using the Jacob and Lohman method for 29 to 34 ft. finished diameter shafts.

(Cb Shale Oil Project, 1978 and 1979, Reinjection Application Permit, prepared by ECA Associates.)

Table 54

C-b Tract Well 32X-12

Aquifer No.	Assigned Permeability (md)
1	15
2	75
3	30
4	130
5	1600
6	400
7	725
8	260
9	260
10	190
11	210
12	280
13	85
14	100
15	75
16	140
17	550
18	825

C-b Tract Well 33X-1

Aquifer No.	Assigned Permeability (md)
1	?
2	?
3	?
4	90
5	130
6	260
7	80
8	550
9	190
10	140
11	260
12	75
13	75
14	100
15	100
16	710
17	250

(ECA)

Table 55

Aquifer Definition
Cb Tract - Well 33X - 1

Aquifer No.	Top of Aquifer[1] (ft)	Thickness[1] (ft)	Est. Transmissivity[1] (GPD/ft)	Equilibrium Pressure[2] (psi)	TDS[3] (mg/l)	Fluoride[3] (mg/l)	Boron[4] (mg/l)	Horiz. Perm. km d
1	350	50	?	22	1050[4]	0.1[4]	0.08[4]	?
2	650	65	?	144	1050[4]	0.1[4]	0.08[4]	?
3	750	60	?	186	1050[4]	0.1[4]	0.08[4]	?
4	900	25	40	244	1050[4]	0.1[4]	0.08[4]	90
5	943	47	11.3	267	1050[4]	0.1[4]	0.08[4]	130
6	1080	20	93	320	540	12	1.2	260
7	1130	45	67	347	750	16	1.4	80
8	1210	34	340	380	995	10	0.3	550
9	1315	25	87	423	680	18	1.8	190
10	1385	30	200	465	735	10	0.7	140
11	1504	21	100	504	581	17	0.5	260
12	1620	55	73	562	800	20	0.5	75
13	1680	30	40	582	1150	25	1.4	75
14	1815	35	67	642	2175	25	1.1	100
15	1850	55	100	661	595	8.9	0.9	100
16	1905	14	180	676	1480	20	1.8	710
17	1950	90	400	712	2500	45	0.9	250

1) As shown by the Pump/Spinner test of 5-7-77; all depths are measured from the kelly bushing

2) Computed from hydrostatic gradient to the midpoint of the aquifer from a static water level at 350 ft.

3) Based on stratigraphic correlation to water samples taken during the drill-stem tests on SG-17

4) Based on the Uinta water sample from 33X-1

(Cb Shale Oil Project, 1978 and 1979, Reinjection Application Permit, ECA Associates)

Table 56

Table 57

BASIC INPUT DATA FOR MODELLING, TRACT C-b

	NUMERICAL VALUE		Reinjection Report
DESCRIPTION OF DATUM	Upc_2 UNIT	Lpc_3 UNIT	SOURCE OF DATA
Transmissivity (GPD/ft)	292	283	Appendix B
Storativity (ft/ft)	175×10^{-6}	155×10^{-6}	Appendix B
Original Pressure (psi)	325	410	Section 10e.
Thickness (ft)	210	445	Section 10e.i.
Injection Gradient (psi/ft)	0.75	0.75	Section 10f.
Injection Well Data	---	---	Section 10f.
Mine Development Schedule	---	---	Figure A-2

(Cb Shale Oil Project, 1978, Reinjection Application Permit, prepared by ECA Associates.)

MIS RETORT ZONE, TRACT Cb, PERFORATION SUMMARY

UPC2 WELLS

Well	Thickness Perforated in Feet
SG-1A	200
SG-6 #1	200
SG-9 #2A	96
SG-11 #2	195
SG-20 #2	70
Cb-1	200
Cb-3	112
Cb-4	130
SG-17#2	54
SG-18A #2	165
SG-21 #3	185

LPC3 WELLS

Well	Thickness Perforated in Feet
SG-1 #1	180
SG-6 #2	40
SG-9 #1	238
SG-10	90
SG-11 #1	70
SG-17 #1	280
SG-18A #1	421
SG-20 #1	440
SG-21 #2	430
AT-18 #1	70

Table 58

WATER QUALITY ANALYSIS
DRILLING WATER

Well Number: SG-11 (Unless otherwise stated, all units are mg/l)
Location: 12'FSL&160'FEL Sec. 7 T3SR96W Elevation: 6900 Grd.

	Element Measured	Depth at Which Sample Taken (ft.)					
		808	868	1330	1385	2465	2825
1.	Aluminum	0.6	2	2	6	.03	.02
2.	Ammonia		0.9	<.1	0.3		.2
3.	Arsenic	.03	.02	.03	.02	.01	.02
4.	Barium	.04	.04	.03	.02	.2	0.06
5.	Beryllium	<.001	<0.1	<.009	<.001	<.002	.001
6.	Bicarbonate	441	383	620	564	1036	973
7.	Bismuth	<.001	<.001	<.009	<.009	<.002	<.001
8.	Boron	<.1	<.1	1.0	1.6	0.4	<.1
9.	Cadmium	<.001	<.01	<.009	<.009	<.002	<.001
10.	Calcium	59	33	89	26	18	36
11.	Carbonate	9	8	2	14	26	43
12.	Cerium	<.001	<.001	<.009	<.009	.001	<.001
13.	Chloride	8	6	5	3	101	68
14.	Chrome, Hexavalent	<.01	<.01	<.01	<.01	<.01	<.01
15.	Cobalt	.02	.02	.006	.008	.06	.03
16.	Conductivity, Specific						
17.	Copper	.3	.06	.01	.009	.04	.007
18.	Fluoride	0.4	1.6	4.4	12	14	10
19.	Gallium	.01	<.001	<.009	.008	<.001	<.001
20.	Hardness, Total	350	250	580	140	67	115
21.	Hydroxide	<.1	<.1	<.1	<.1	<.1	<.1
22.	Iron	<.05	<.05	<.05	<.05	<.05	<.05
23.	Lead	<.05	<.05	.04	<.009	0.05	.09
24.	Lithium	.4	.06	.03	.1	<.5	<.001
25.	Magnesium	43	33	78	18	15	25
26.	Manganese	<.05	<.05	.05	<.05	<.05	<.05
27.	Mercury	<.01	<.01	<.01	<.01	<.01	<.01
28.	Molybdenum	0.2	<.001	.2	<.009	<.05	.01
29.	Nickel	.07	.01	.01	.01	0.1	.06
30.	Nitrate	1.7	3.5	<.1	<.1	<.1	<.1
31.	pH	8.4	8.4	8.2	8.5	8.6	8.8
32.	Phosphate, Total	<.1	<.1	<.1	<.1	<.1	<.1
33.	Potassium	0.6	0.8	1.3	1.2	1.5	1.8
34.	Selenium	<.001	<.001	<.009	<.009	<.002	<.001
35.	Silica	24	21	19	11	17	10
(*) 36.	Silver	<.001	<.001	<.009	<.009	<.002	
37.	Sodium	165	141	215	211	488	500
38.	Solids, Dissolved	841	634	1150	659	1244	1382
39.	Strontium	7	3	1	0.5	1	1
40.	Sulfate	316	202	433	86	56	199
41.	Titanium	.2	.1	0.1	.04	.2	.07
42.	Vanadium	.01	.003	.007	.003	<.001	<.001
43.	Yttrium	<.001	<.001	.005	<.009	<.001	<.001
44.	Zinc	.06	0.1	.2	.03	.08	<.3
45.	Zirconium	<.001	<.001	<.009	<.009	<.003	.003
46.	Radioactivity Gross Alpha (pcl)						
	Radium 226*						
	Gross Beta (pcl)						
	Thorium 230**						
	Uranium**						
47.	Total Organic Carbon (TOC) If TOC > 10 mg/l then measure Dissolved Organic Carbon						
	Suspended Organic Carbon						
	Phenols	<.005	<.001	<.001	<.001	<.001	<.01
	Sulfate, Acid Extraction						
	Nitrogen, Base Extraction						

(*) Not required
* Required if gross alpha is greater than 4 picocuries per liter (pcl).
** Required if gross beta is greater than 100 picocuries per liter (pcl).

(Cb Shale Oil Venture, 1974, Summary Quarterly Reports #1 through #9.)

Table 59

WATER QUALITY SAMPLES

JETTING TESTS AND DRILL STEM TESTS

Well	Test	Sample Depth Feet
SG-1	JT	613
SG-1	JT	706
SG-1	JT	990
SG-1	JT	1105
SG-1	JT	2179
SG-1	JT	2525
SG-1	DST	lower zone (below 1930)
SG-20	JT	515
SG-20	JT	850
SG-20	JT	987
SG-20	DST	945
SG-21	JT	676
SG-21	JT	980
SG-21	JT	1035
SG-21	DST	1000-1035
SG-21	DST	950-1009
SG-8	JT	600
SG-8	JT	971
SG-8	JT	1013
SG-8	JT	2117
SG-8	JT	2608
SG-8	DST	lower zone (below 1910)
SG-8	DST	upper zone (950 to surface)

JT = Jetting Tests
DST = Drill Stem Tests

(ibid.)

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Table 60

Water Quality Samples Collected During The Drilling of SG-17

Sample No.	Drill Stem Test No.	Sample Interval (Feet)	Sample Type
1	DST 1	788-808	Environmental (1)
2		859	Minimum (2)
3	DST 3	822-869	Minimum
4	DST 4	866-919	Minimum
5	DST 5	919-970	Minimum
6	DST 6	970-1017	Minimum
7	DST 7	1015-1062	Environmental
8	DST 8	1066-1117	Environmental
9	DST 9	1115-1166	Minimum
10		1180	Minimum
11	DST 10	1164-1212	Minimum
12	DST 11	1200-1224	Minimum
13	DST 13	1224-1250	Minimum
14	DST 14	1250-1271	Minimum
15	DST 15	1280-1309	Minimum
16	DST 17	1329-1374	Minimum
17	DST 18	1374-1419	Minimum
18	DST 19	1423-1470	Minimum
19	DST 21	1473-1522	Minimum
20	DST 23	1514-1752	Minimum
21	DST 24	1561-1622	Minimum
22	DST 25	1618-1670	Minimum
23		1622	Minimum
24	DST 26	1668-1720	Minimum
25	DST 27	1711-1770	Minimum
26	DST 28	1768-1820	Minimum
27	DST 29	1818-1870	Minimum
28	DST 30	1869-1920	Minimum
29	DST 31	1918-1970	Minimum
30	DST 34	2120-2170	Environmental
31		2608	Minimum

(1) Complete chemical analysis per environmental baseline samples.
(2) Minimum analysis done.

(Cb Shale Oil Venture, 1974, Summary Quarterly Reports #1 through #9.)

Table 61

FIELD DATA - DEEP WELL SAMPLING

Well String Number	Depth to water at Start	Depth to water at Finish	Conductivity Range	Final Conductivity	°C Temp.	Gallons of water Swabbed	pH
SG-1, #1	69.8	155.1	3000-10,000	8250	17	1260	7.8
SG-1, #2	62.8	65.8	1200-1500	1250	14	2840	7.5
SG-9, #1	362.0	430.6	1300-3400	2000	22	2100	8.0
SG-9, #2	250.8	371.6	1850-2100	1850	15	1150	7.4
SG-21	108.1	109.1	750-1150	1000	16	3210	-
Cb-4	424.6	425.3	800-900	825	15	2300	7.9
SG-11, #1R	405.6	500	14,000-32,000	22,000	19	1220	7.5
SG-11, #2	358.8	500	800-4000	1200	17	530	8.1
SG-11, #3	354.6	500	1600-1800	1790	15	300	7.1
SG-18A	490.1	500	750-1250	1000	18	--	7.7
Cb-2	329.6	242.2	1600-1650	1600	14	2920	7.8
SG-6, #1	394.3	790.0	1800-3100	3000	16	550	8.0
SG-6, #2	376.5	503.4	1300-1400	1300	16	630	8.1
SG-6, #3	337.2	329.5	1350-1550	1550	16	160	8.7
AT-1c, #1	381.2	383.6	1300-1430	1430	16	160	9.3
AT-1c, #2	382.7	500	1200-1300	1250	18	780	8.7
AT-1c, #3	355.1	362.8	1300-1400	1400	19	1320	7.8
Cb-1	357.0	494.5	2200-3800	3550	19	1390	7.8
SG-10A	371.4	372	1400-1500	1500	14	--	7.9
SG-10R	410.0	500	3500-3800	3800	16	290	6.7
SG-19	8.2	4.1	2000-2400	2300	21	1540	7.8
SG-20	Flowing	Flowing	2000-2600	2000	21	4070	7.9
SG-17, #1R	407.9	418.5	4800-5500	5500	21	2580	7.8
SG-17, #2	400.0	427.5	1150-1450	1250	20	2170	8.2
SG-8R	Flowing	8.7	1900-1950	1900	22	2280	8.0

(Cb Shale Oil Venture, 1976, Environmental Baseline Program,
Volume II, Final Report, Hydrology.)

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Table 62

PARAMETER	SYMBOL	DAILY	WEEKLY	MONTHLY	QUARTERLY	ANNUALLY	ANNUALLY
Alkalinity	CaCO3					●	
MO Alkalinity	PA						
P Alkalinity	PA						
Aluminum	Al					●	
Ammonia	as NH3						
Antimony						●	
Arsenic	As					●	
Bacteria	SB						
Barium	Ba						
Beryllium	Be					●	
Bicarbonate	HCO3					●	
Biological Oxygen Demand	BOD					●	
Bismuth	Bi						
Boron	B					●	
Bromide	Br					●	
Cadmium	Cd						
Calcium	Ca					●	
Carbonate	CO3					●	
Chemical Oxygen Demand	COD					●	
Chloride	Cl					●	
Chromium	Cr					●	
Cobalt	Co					●	
Coliform, Fecal						●	
Coliform, Total							
Color (not precise)							
[illegible]	CP						
Conductivity, Specific	SPC						
Copper	Cu					●	
Cyanide	CN						
Dissolved Oxygen	DO						
Element Scan							
Fecal Streptococcus							
Flow							
Fluoride	F					●	
Gallium	Ga					●	
Germanium	Ge						
Hardness (as Mg)						●	
[illegible]	OH						
Iodine	I						
Iron	Fe					●	
Kjeldahl Nitrogen						●	
Lead	Pb					●	
Level				■			
Lithium	Li					●	
Magnesium	Mg					●	
Manganese	Mn					●	
Mercury	Hg					●	
Methylene Blue Active Substance	MBAS						
Molybdenum	Mo					●	
Nickel	Ni					●	
Nitrate	NO3					●	
Nitrite	NO2						
Odor							
Oil & Grease	O&G					●	
Organic Carbon, Dissolved	DOC					●	
Organic Carbon, Total	TOC						
Ortho-Phosphorus (Phosphate)	PO4						
Pesticides							
pH	pH					●	
Phenols						●	
Fish	FSH						►
Potassium	K					●	
Rubidium	Rb						
Sediment Characterization							
Selenium	Se					●	
Scandium	Sc						
Silica	SiO2						
Silver	Ag					●	
Sodium	Na					●	
Solids, Dissolved	TDS					●	
Solids, Suspended	TSS						
Strontium	Sr					●	
Surfactants							
Sulfate	SO4					●	
Sulfite	SO3						
Temperature (°C)							
Thiosulfate	S2O3						
Tin	Sn						
Titanium	Ti						
Tungsten	W						
Turbidity							
Vanadium	V						
Yttrium	Y						
Zinc	Zn					●	
Zirconium	Zr						
Radioactivity							
Gross Alpha (pCi/l)						●	
Radium 226	Ra226					●	
Natural Uranium	U						
Gross Beta						●	
Cesium	Cs137						
Sr90							
Thorium 230	Th230						
Uranium	U						
Fractionation of Organic Carbon into:							
a. Hydrophobic Bases							
b. Hydrophobic Acids							
c. Hydrophobic Neutrals							
d. Hydrophilic Bases							
e. Hydrophilic Acids							
f. Hydrophilic Neutrals							

- C-b affiliated (DMP and WAP stations)

WY01	WY17	WY52	WY62
WY10	WY45	WY54	WY81
WY12	WY46	WY61	WY91

(Cb Shale Oil Project, 1979, Development Monitoring Program for Tract Cb)
Revised 1/15/80.

Non-affiliated (Additional WAP stations)

TH75-5B	TH75-9B	TG71-3	Liberty Bell 12
TH75-13B	Equity Sulfur 1A	TG71-5	Getty 5-4D
Equity 1	CER X8-D-03	Oildland 3	TG71-4
TH75-18B	TH75-15B	CF-17X-RC	Equity SS 13
TH75-10B	Greene 4-4	Burr 25	

Table 63

SYMBOLS

- ● Applies to all C-b affiliated stations
- ► Applies to stations and species to be identified
- ■ Applies to both C-b affiliated and non-affiliated stations

[illegible]	[illegible]							
P Alkalinity	PA							
Aluminum	Al					●		
Ammonia	NH3					●		
Antimony								
Arsenic	As					●		
Bacteria	SB							
Barium	Ba					●		
Beryllium	Be							
Bicarbonate	HCO3					●		
Biological Oxygen Demand	BOD					●		
Bismuth	Bi							
Boron	B					●		
Bromide	Br					●		
Cadmium	Cd							
Calcium	Ca					●		
Carbonate	CO3					●		
Chemical Oxygen Demand	COD					●		
Chloride	Cl					●		
Chromium	Cr					●		
Cobalt	Co					●		
Coliform, Fecal								
Coliform, Total								
Color (not precise)								
Conc. hydrocarbon	CH							
Conductivity, specific	SpC					●		
Copper	Cu					●		
Cyanide	CN							
Dissolved Oxygen	DO							
Element Scan								
Fecal Streptococcus								
Flow								
Fluoride	F					●		
Gallium	Ga							
Germanium	Ge							
Hardness (Ca, Mg)						●		
Hydrocarbons	CH							
Iodine	I							
Iron	Fe					●		
Kjeldahl Nitrogen						●		
Lead	Pb					●		
Level				■				
Lithium	Li					●		
Magnesium	Mg					●		
Manganese	Mn					●		
Mercury	Hg					●		
Methylene Blue Active Substance	MBAS							
Molybdenum	Mo					●		
Nickel	Ni					●		
Nitrate	NO3					●		
Nitrite	NO2							
Odor								
Oil & Grease						●		
Organic Carbon, Dissolved	DOC					●		
Organic Carbon, Total	TOC							
Ortho-Phosphorus (Phosphate)	PO4							
Pesticides								
pH	pH					●		
Phenols						●		
[illegible]	[illegible]						►	
Potassium	K					●		
Radium	Ra							
Sediment Characterization								
Selenium	Se					●		
Scandium	Sc							
Silica	SiO2							
Silver	Ag					●		
Sodium	Na					●		
Solids, Dissolved	TDS					●		
Solids, Suspended	TSS							
Strontium	Sr					●		
Surfactants								
Sulfate	SO4					●		
Sulfide	S=							
Temperature (°C)								
Thiosulfate	S2O3							
Tin	Sn							
Titanium	Ti							
Tungsten	W							
Turbidity								
Vanadium	V							
Yttrium	Y							
Zinc	Zn					●		
Zirconium	Zr							
Radioactivity								
Gross Alpha (pCi/l)						●		
Radium 226	Ra226					●		
Natural uranium	U							
Gross beta						●		
Cesium	Cs137							
Sr90								
Thorium 230	Th230							
Uranium	U							
Fractionation of Organic Carbon Test								
a. Hydrophobic bases								
b. Hydrophobic acids								
c. Hydrophobic neutrals								
d. Hydrophilic bases								
e. Hydrophilic acids								
f. Hydrophilic neutrals								

- C-b affiliated (DMP and WAP stations)

WX02	WX10	WX18	[illegible]	WX35
WX03	WX12	WX19	[illegible]	WX63
WX04	WX17	WX26	[illegible]	WX92
		WX21		

Non-affiliated (Additional WAP stations)

TH75-5A	TH75-9A	Greene [illegible]	Nute 25
TH75-13A	CIR 86-D-02	Oldland 3	Liberty Bell 12
TH75-18A	TH75-15A	CP-17X-pC	Union 81

Revised 1/15/80.

SYMBOLS

● Applies to all C-b affiliated stations.
► Applies to stations and species to be identified.
■ Applies to both affiliated and non-affiliated stations.

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Table 63 (cont.)

CB-TRACT
WATER QUALITY PARAMETERS
UPPER AQUIFERS
FOR SAMPLE DATA SHOWN

WELL	YR	MO	MO (MG/L)	NI (MG/L)	NO3 (MG/L)	OIL AND GREASE (MG/L)	DOC (MG/L)	PHEN (MG/L)	K (MG/L)	CU (MG/L)	TOTAL DISS SOLIDS (MG/L)	SR (MG/L)	SO4 (MG/L)	LI (MG/L)	MN (MG/L)	FE (MG/L)
WA02	79	12	.010	-.020	59.00	7.0	5.1	.0290	4.0	-.020	1000.0	1.9	340.0	.07	.020	.02
WA04	79	12	-.020	-.020	120.00	1.0	7.1	.0050	.5	-.020	400.0	6.3	100.0	-.05	.060	.08
WA12	79	12	-.020	-.020	25.00	1.0	1.0	-.0010	.6	-.020	800.0	7.7	120.0	-.05	.080	-.02
WA17	79	12	-.020	-.020	10.00	1.0	-1.0	.0300	3.1	-.020	900.0	1.1	-5.0	-.05	.030	-.02
WA18	79	12	-.020	-.020	16.00	2.0	2.0	.0010	.4	-.020	430.0	3.4	6.0	-.05	-.020	-.02
WA19	79	12	-.020 -.020	-.020 -.020	5.00 -.10	15.0 7.0	10.0 3.2	-.0010 .0230	1.2 1.0	-.020 -.020	1000.0 1000.0	1.0 1.7	8.0 6.0	.08 .07	-.020 -.020	-.02 -.02
WA21	79	12	-.020	-.020	-.10	5.0		-.0010	.3	-.020	670.0	11.0	150.0	-.05	.020	-.02
WA44	79	12	-.020	-.020	100.00	20.0	4.1	.0140	3.1	-.020	940.0	9.4	310.0	.06	.100	.02
WA55	79	12	.010	-.020	.10	4.0	16.4	-.0010	4.0	-.020	640.0	3.2	6.0	.05	.020	.03
WA63	79	12	.060	-.020	75.00	14.0	3.0	.0160	1.6	-.020	750.0	.6	5.0	.05	-.020	-.02
WA92	79	12	-.020	-.020	420.00	2.0		.0160	3.0	-.020	1400.0	8.5	620.0	.08	.400	.90

NOTE: - INDICATES LESS THAN

(Cb Shale Oil Project, 1979, Development Monitoring Program for Tract Cb.)

Table 64

CH-TRACT
WATER QUALITY PARAMETERS
UPPER AQUIFERS
FOR SAMPLE DATA SHOWN

WELL	YR	MO	N KJELD. (MG/L)	TOTAL ALPHA PCI/L)	TOTAL BETA PCI/L	RADIUM 226 PCI/L	HARDNESS (MG/L CACO3)	HG (MG/L)	SE (MG/L)	AG (MG/L)	CU (MG/L)	B (MG/L)	ZN (MG/L)	PB (MG/L)	F (MG/L)	CL (MG/L)	CN (MG/L)
WA02	79	12	1.1	4.6	57.0	1.4	39.0	-.02000	.030	-.010	-.020	.10	-.020	-.020	.90	5.2	-.020
WA04	79	12	.8	.8	6.0		130.0	-.02000	-.020	-.020	-.020	.10	-.020	.040	.40	16.0	-.020
WA12	79	12	.3	1.5			150.0	-.02000	-.020	-.010	-.020	.30	.020	-.020	9.80	3.2	-.020
WA17	79	12	.7	12.0	6.0		25.0	-.02000	-.020	-.010	-.020	1.30	.070	-.020	19.00	2.0	.020
WA14	79	12	2.2	4.5	20.0	1.7	69.0	-.02000	.020	-.010	-.020	1.10	-.020	-.020	5.90	4.2	-.020
WA19	79	12	1.4 4.2	2.3 6.0	3.0 10.0		28.0 27.0	-.02000 -.02000	-.020 -.020	-.010 -.010	-.020 -.020	1.70 1.30	.100 .040	-.020 -.020	23.00 23.00	1.6 1.8	-.020 -.020
WA21	79	12	.3				170.0			-.020	-.020	.20	.030	.030	7.20	2.8	-.020
WA44	79	12	.8	12.0	58.0	.3	300.0	-.02000	.040	-.010	-.020	.20	-.020	.040	4.40	4.6	-.020
WA35	79	12	.3	6.0	6.0		36.0	-.02000	-.020	-.010	-.020	.50	-.020	-.020	18.00	8.0	-.020
WA51	79	12	.6	12.0	11.0		15.0	-.02000	.040	-.010	-.020	.60	.030	-.020	16.00	4.0	-.020
WA42	79	12	.3				690.0			-.020	-.020	.20	.030	.040	.40	3.6	-.020

NOTE: - INDICATES LESS THEN

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Table 64 (cont.)

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WATER LEVELS IN ADDITIONAL WELLS MONITORED UNDER THE WATER AUGMENTATION PLAN

WELL LEVELS

WATER LEVELS IN UPPER AQUIFER WELLS

WELL ID - MEASURING POINT ELEVATION (FT)

		WX64	WX65	WX67	WX69	WX71	WX72	WX73	WX75
		7178	6390	6740	7350	6580	6805	8142	7583
YR	MO	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)
79	8	6757	6332	6310	6884	INACCS	6760		
	9							7641	7510
	10	6758	6331	6309	6897	INACCS	6759	7647	7512
	11	6758	6332	6308	6898	INACCS	6159	7647	7512
	12	6759	6333	6309	6897	INACCS	6760	7646	

WATER LEVELS IN LOWER AQUIFER WELLS

WELL ID - MEASURING POINT ELEVATION (FT)

		WY64	WY65	WY66	WY67	WY68	WY69	WY70	WY71	WY72	WY75	WY76	WY77	WY78	WY79
		7178	6390	6286	6740	6840	7350	7070	6580	6805	6820	6865	7777	7145	7020
YR	MO	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)
79	8	6423	6313	FLWING	6235	6511	7038	INACCS	INACCS	6773			FLWING	7073	INACCS
	9										6769	FLWING			
	10	6444	6313	FLWING	6235	6510	6886	INACCS		6773	6770	FLWING	FLWING	7075	INACCS
	11	6445	6313	FLWING	6235	6509	6886	INACCS	INACCS	6773	6769	FLWING	FLWING	7073	INACCS
	12	6444	6313	FLWING	6235	6510	6885	INACCS	INACCS	6773	6769	FLWING	FLWING	7072	INACCS

WATER LEVELS IN COMPOSITE WELLS

WELL ID - MEASURING POINT ELEVATION (FT)

		WV01	WV02	WV03	WV04	WV05
		6411	6490	6729	0	7420
YR	MO	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)	DEPTH (FT)
79	8		FLWING	FLWING		
	9	6285			FLWING	7354
	10	6286	FLWING	FLWING	FLWING	7354
	11	6286	FLWING	FLWING	FLWING	7354
	12	6286	FLWING	FLWING	FLWING	7353

PLUGGD = WELL PLUGGED
DRY = WELL DRY
FLWING = WELL FLOWING
INACCS = WELL INACCESSABLE

Table 65

CB-TRACT
WATER QUALITY PARAMETERS
UPPER AQUIFERS
FOR SAMPLE DATA SHOWN

WELL	YR	MO	TOTAL ALK (MG/L CACO3)	AL (MG/L)	AMMONIA AS N (MG/L)	AS (MG/L)	BA (MG/L)	HCO3 (MG/L CACO3)	CO3 (MG/L CACO3)	BOD (MG/L)	COD (MG/L)	BR (MG/L)	NA (MG/L)	MG (MG/L)	CA (MG/L)	SODIUM ABSORPTION RATIO (ME/L)
WA02	79	12	500.0	-.100	-.040	-.020	-.50	380.0	120.0	6.6	13.0	-.100	370.0	4.7	7.8	25.839
WA04	79	12	310.0	-.100	.600	-.020	-.50	250.0	60.0	6.6	6.0	-.100	110.0	19.0	21.0	4.189
WA12	79	12	500.0	-.100	.700	-.020	-.50	410.0	90.0	67.0	6.0	-.100	240.0	27.0	17.0	8.432
WA17	79	12	750.0	-.100	1.300	-.020	-.50	620.0	130.0	74.0	2.0	-.100	380.0	2.9	5.2	33.120
WA18	79	12	400.0	-.100	-.040	-.020	-.50	300.0	100.0	1.4	4.0	-.100	140.0	14.0	4.6	7.334
WA19	79	12	1400.0 400.0	-.100 -.100	2.200 1.200	-.020 -.020	3.20 3.40	1200.0 330.0	200.0 68.0	14.0 2.0	2.0 57.0	-.100 -.100	700.0 730.0	2.8 2.7	6.7 6.4	57.286 61.008
WP21	79	12	390.0	-.100	.200	-.020	-.50	310.0	80.0	2.0	2.0	-.100	160.0	27.0	25.0	5.287
WP44	79	12	470.0	-.100	.200	-.020	1.40	350.0	120.0	13.0	23.0	-.100	220.0	44.0	47.0	5.543
WA55	79	12	600.0	.100	.200	.040	1.30	470.0	130.0	8.0	10.0	-.100	280.0	5.0	6.1	20.363
WA63	79	12	600.0	-.100	1.100	-.020	-.50	340.0	260.0	19.0	17.0	-.100	260.0	1.5	3.4	29.537
WP92	79	12	610.0	-.100	.200	-.020	1.00	610.0	-1.0	2.4	42.0	-.100	210.0	120.0	78.0	3.484

NOTE: - INDICATES LESS THEN

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Table 65(cont.)

LOWER AQUIFER WELLS SHOWING MEAN QUARTERLY WATER ELEVATIONS VS. BASELINE

Computer Code	Station	Baseline Average	January-March, 1979		April-June, 1979		July-September, 1979		October-December, 1979	
			Elevation	Elevation-Baseline	Elevation	Elevation-Baseline	Elevation	Elevation-Baseline	Elevation	Elevation-Baseline
WY01	CB-1	6408	6403	-5	6403	-5	6400	-8	6395	-13
WY10	SG-10R	6539	6537	-2	6579	40	6578	39	6569	30
WY12	SG-1-1	6358	6354	-4	6351	-7	6354	-4	6354	-4
WY17	SG-17-1R	6636	6648	12	6650	14	6645	9	6645	9
WY45	AT-1C-1	6517	6514	-3	6514	-3	6512	-5	6512	-5
WY46	AT-1C-2	6519	6515	-4	6514	-5	6513	-6	6513	-6
WY52	SG-11-1R	6507	6522	15	6519	12	6523	16	6524	17
WY54	SG-11-2	6540	6547	7	6544	4	6544	4	6543	3
WY61	SG-6-1	6506	6549	43	6524	18	6548	42	6545	39
WY62	SG-6-2	6513	6503	-10	6514	1	6499	-14	6509	-4
WY91	SG-9-1	6510	6522	12	6512	2	6510	0	6506	-4

Table 65 (cont.)

UPPER AQUIFER WELLS SHOWING MEAN QUARTERLY WATER ELEVATIONS VS BASELINE

(FEET)

Location			January-March 1979		April-June 1979		July-September 1979		October-December 19	
Computer Code	Station	Baseline Average*	Elevation	Elevation - Baseline	Elevation	Elevation - Baseline	Elevation	Elevation - Baseline	Elevation	Elevati Baseli
WX02	Cb-2	6404	6401	-3	6397	-7	6391	-13	6386	-18
WX04	Cb-4	6617	6629	12	6629	12	6633	16	6661	44
WX10	SG-10A	6576	6580	4	6559	-17	6539	-37	6553	-23
WX12	SG-1-2	6365	6366	1	6364	-1	6360	-5	6356	-9
WX17	SG-17-2	6640	6636	-4	6638	-2	6644	4	6639	-1
WX19	SG-19	6375	6371	-4	— NO DATA —		6366	-9	6362	-13
WX20	SG-20	6358	6358	0	6358	0	6352	-6	6347	-11
WX21	SG-21	6705	6706	1	6707	2	6702	-3	6734	29
WX44	AT-1C-3	6547	6540	-7	6541	-6	6538	-9	6535	-12
WX55	SG-11-3	6546	6564	18	6560	14	6556	10	6556	10
WX63	SG-6-3	6546	6511	-35	6510	-36	6508	-38	6505	-41
WX92	SG-9-2	6515	6499	-16	6511	-4	6508	-7	6508	-7
WX32	32X-12	6473***	6470	-3	6473	0	6453	-20	6434	-39
WX33	33X-1	6380**	6378	-2	6362	-18	6315	-65	6331	-49

* - Mean Elevation computed using data from 10/74-12/78
** - Mean Elevation computed using data from 6/78- 3/79
*** - Mean Elevation computed using data from 9/77-12/78

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Table 65 (cont.)

SECTION 2

MINERALOGY TABLES

TABLE 66

MINERALS OF THE GREEN RIVER FORMATION IN THE GREEN RIVER-WASHAKIE BASIN COMPLEX

Mineral	Formula	Reference
Elements		
Sulfur	S	Milton (1971), Bradley (1964)
Sulfides		
Pyrite	FeS_2	Milton & Eugster (1959)
Pyrrhotite	$Fe_{1-x}S$	Milton & Eugster (1959)
Wurtzite	ZnS	Milton et al. (1955)
Marcasite (2°)	FeS_2	Milton (1958, unpub.)
Halides		
Neighborite	$NaMgF_3$	Chao (1961)
Halite	$NaCl$	Deardorff (1963)
Oxides		
Quartz	SiO_2	ub
Chalcedony	$SiO_2 \cdot H_2O$	ub
Anatase (detrital)	TiO_2	Bradley & Eugster (1969)
Carbonates		
Calcite	$CaCO_3$	ub
Dolomite	$CaMg(CO_3)_2$	ub
Nahcolite	$NaHCO_3$	Ertl (1947)
Trona	$Na_3(CO_3)(HCO_3) \cdot 2H_2O$	Smith & Young (1969), Fahey (1939), Deardorff (1963)
Thermonatrite	$Na_2CO_3 \cdot H_2O$	Fahey (1958, unpub.)
Natron	$Na_2CO_3 \cdot 10H_2O$	Milton & Fahey (1960)
Strontianite	$SrCO_3$	Milton (1971)
Aragonite	$CaCO_3$	Smith & Trudell (1968)

TABLE 66 (cont.)

Mineral	Formula	Reference
Witherite	$MgCO_3$	Bradley (1929a)
Siderite	$FeCO_3$	Milton (1958, unpub.)
Shortite	$Na_2Ca_2(CO_3)_3$	Fahey (1939)
Pirssonite	$Na_2Ca(CO_3)_2 \cdot 2H_2O$	Fahey (1941)
Gaylussite	$Na_2Ca(CO_3)_2 \cdot 5H_2O$	Fahey (1941)
Barytocalcite	$BaCa(CO_3)_2$	Milton (1958, unpub.)
Norsethite	$MgBa(CO_3)_2$	Mrose et al. (1960)
Mackelveyite	$(Na,Cu)(Ba,Y,V)_2(CO_3)_3 \cdot 1\text{-}2H_2O$	Milton et al. (1965)
Eitelite	$Ba(Ce,Y,Na,Ca)(CO_3)_2$	Donnay & Preston (1971)
Burbankite	$(Na,Ca,Sr,Ba,Ce)_6(CO_3)_5$	Fitzpatrick (1977)
Bradleyite	$MgNa_3CO_3PO_4$	Fahey (1941)
Northupite	$Na_3Mg(CO_3)_2Cl$	Fahey (1941)
Tychite	$Na_6Mg_2(CO_3)_4(SO_4)$	Milton (1971)
Burkeite	$Na_6(CO_3)(SO_4)_2$	Milton (1971)
Wegscheiderite	$Na_5(CO_3)(HCO_3)_3$	Fahey (1963)
Silicates		
Kaolinite	$Al_2Si_2O_5(OH)_4$	Regis and Sand (1957)
Illite	$(K,H_3O)(Al,Mg,Fe)_2(Al,Si)_4O_{10}[(OH)_2,H_2O)]$	Regis and Sand (1957)
Montmorillonite (Smectite)	$(Na,Ca)_{.33}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$	Regis and Sand (1957)
Sepiolite	$Mg_4Si_6O_{15}(OH)_2 \cdot 6H_2O$	Bradley (1929a)
Talc	$Mg_3Si_4O_{10}(OH)_2$	Bradley (1964)
Chlorite	$(Mg,Fe)_{5-6}(Al,Si)_4O_{10}(OH)_8$	Bradley (1964)
Lazurite	$(Na,Ca)_8(Al,Si)_{12}O_{24}S$	Bradley (1964)
Stevensite	$Mg_3Si_4O_{10}(OH)_2$	Bradley & Fahey (1962)
Loughlinite	$Na_2Mg_3Si_6O_{16} \cdot 8H_2O$	Fahey (1960)
Searlsite	$NaBSi_2O_6 \cdot H_2O$	Fahey (1950)
Leucosphenite	$BaNa_4Ti_2B_2Si_{10}O_{30}$	Pabst & Milton (1972)
Labuntsovite	$(K,Ba,Na)(Ti,Nb)(Si,Al)_2(O,OH) \cdot H_2O$	Milton et al. (1958)
Acmite	$NaFeSi_2O_6$	Clark et al. (1969)
Mg-Riebeckite	$Na_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Milton & Eugster (1959)
Biotite	$K(Fe,Mg)_3AlSi_3O_{10}(OH)_2$	Milton (1971)

TABLE 66 (cont.)

Mineral	Formula	Reference
Orthoclase	$KAlSi_3O_8$	Smith & Trudell (1968)
Albite	$NaAlSi_3O_8$	Moore (1950)
Analcime	$NaAlSi_2O_6 \cdot H_2O$	Bradley (1929a)
Clinoptilobite	$(Na,K,Ca)_{2-3}Al_3(Al,Si)_2Si_{13}O_{36} \cdot 12H_2O$	Goodwin and Surdam (1967)
Mordenite	$(Ca,Na_2,K_2)(Al_2Si_{10})O_{24} \cdot 7H_2O$	Goodwin and Surdam (1967)
Sulfates		
Celestite (2°)	$SrSO_4$	Milton (1971)
Gypsum (2°)	$CaSO_4 \cdot 2H_2O$	Milton (1971)
Phosphates		
Uraniferous Fluorapatite		Love (1964)
Fluorapatite	$Ca_{10}(PO_4)_6F_2$	Milton (1958, unpub.)
Collophane	$Ca_{10}(PO_4)_6CO_3 \cdot H_2O$	Bradley (1929a, b)
Hydrocarbons		
Gilsonite		Crawford (1957)
Uintahite		Hunt et al. (1954)
Utahite		Hunt et al. (1954)
Tabbyte		Hunt et al. (1954)
Ozokerite		Hunt et al. (1954)
Ingramite		Hunt et al. (1954)
Albertite		Milton et al. (1974)
Coal		Hunt et al. (1954)
Abelsonite		Pabst et al. (1975)

TABLE 67

MINERALS OF THE GREEN RIVER FORMATION IN THE UINTA BASIN, UTAH

Mineral	Formula	Reference
Sulfides		
Pyrite	FeS_2	ub
Marcasite (2°)	FeS_2	Milton (1958, unpub.)
Pyrrhotite	$Fe_{1-x}S$	Milton & Eugster (1959)
Wurtzite	ZnS	Milton, Axelrod, Gimaldi (1955a)
Halides		
Neighborite	$NaMgF_3$	Chao et al. (1961)
Oxides		
Quartz	SiO_2	ub
Chalcedony	SiO_2	ub
Anatase (detrital)	TiO_2	Bradley (1931)
Carbonates		
Calcite	$CaCO_3$	ub
Dolomite	$CaMg(CO_3)_2$	ub
Ankerite	$Ca(Fe,Mg,Mn)(CO_3)_2$	Smith & Robb (1966)
Nahcolite	$NaHCO_3$	Chao et al. (1961), Milton et al. (1960a), Milton et al. (1955a), Pabst (1973)
Trona	$Na_3(CO_3)(HCO_3)\cdot 2H_2O$	Pabst (1973)
Wegscheiderite	$Na_5(CO_3)(HCO_3)_3$	Fahey (1963)
Magnesite	$MgCO_3$	Milton (1977) Milton (1971) Bradley (1929b)
Siderite	$FeCO_3$	Desborough (1976) Bradley (1931) Milton (1958, unpub.)

TABLE 67 (cont.)

Mineral	Formula	Reference
Aragonite	$CaCO_3$	Desborough (1976)
Eitelite	$Na_2Mg(CO_3)_2$	Pabst (1973) Milton et al. (1954a) Milton et al. (1960a)
Shortite	$Na_2Ca_2(CO_3)_3$	Milton et al. (1954a,b) Milton et al. (1960a) Milton et al. (1955a,b) Pabst (1973)
Barytocalcite	$BaCa(CO_3)_2$	Chao et al. (1961)
Burbankite	$(Na,Ca,Sr,Be,Ce)_6(CO_3)_5$	Chao et al. (1961)
Northupite	$Na_3Mg(CO_3)_2Cl$	Pabst (1973)
Silicates		
Apophyllite	$KCa_4Si_8O_{20}(F,OH)\cdot 8H_2O$	Bradley (1931)
Illite	$(K,H_3O)(Al,Mg,Fe)_2(Al,Si)_4O_{10}[(OH)_2,H_2O]$	Desborough (1976)
Smectite	$(Na,Ca)_{.33}(Al,Mg)_2Si_4O_{10}(OH)_2\cdot nH_2O$	Desborough (1976)
Sepiolite (Loughlinite?)	$Na_2Mg_3Si_6O_{16}\cdot 8H_2O$	Bradley (1929a) Milton (1960b)
Albite	$NaAlSi_3O_8$	Desborough (1976)
K-Feldspar	$KAlSi_3O_8$	Desborough (1976)
Reedmergnerite	$NaBSi_3O_8$	Milton et al. (1954a, 1955b, 1960a)
Searlsite	$NaBSi_2O_6\cdot H_2O$	Milton et al. (1955a,b) Pabst (1973) Milton et al. (1960a) Milton et al. (1954a)
Garrelsite	$Ba_3NaSi_2B_7O_{16}(OH)_4$	Milton (1955a) Chao et al. (1961)
Leucosphenite	$BaNa_4Ti_2B_2Si_{10}O_{30}$	Milton et al. (1954a,b) Pabst (1973) Pabst & Milton (1972) Milton et al. (1955b)

TABLE 67 (cont.)

Mineral	Formula	Reference
Acmite	$NaFeSi_2O_6$	Milton et al. (1960a)
Magnesio-arfvedsonite	$(Na,Ca)_3(Mg,FeAl)_5(Si,Al)_8O_{22}(OH,F)_2$	Milton et al. (1974)
Elpidite	$Na_2ZrSi_6O_{15}\cdot 3H_2O$	Milton et al. (1960b)
Mg-riebeckite	$Na_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	Pabst (1973)
Analcime	$NaAlSi_2O_6\cdot H_2O$	Milton et al. (1954b) Milton et al. (1960a) Desborough (1976)
Zircon (detrital)	$ZiSiO_4$	Bradley (1951) (ub, from Milton & Eugster, 1959)
Phosphates		
Collophane	$Ca_{10}(PO_4)_6CO_3\cdot H_2O$	Bradley (1951)
Apatite (detrital)	$Ca_{10}(PO_4)_6(F,OH,Cl)$	Bradley (1931)
Hydrocarbons		
Gilsonite		Hunt et al. (1954)
Uintahite		Hunt et al. (1954)
Utahite		Hunt et al. (1954)
Tabbyite		Hunt et al. (1954)
Ozokerite		Morrow (1957)
Ingramite		Hunt et al. (1954)
Abertite		Hunt et al. (1954)
Kerogen		Hunt et al. (1954)
Abelsonite		Milton (1977)

TABLE 68

MINERALS OF THE GREEN RIVER FORMATION IN PICEANCE CREEK BASIN, COLORADO

Mineral	Formula	Reference
Elements		
Sulfur	S	Milton (1971)
Sulfides		
Pyrite	FeS_2	ub
Pyrrhotite	$Fe_{1-x}S$	Milton (1971)
Zinc Sulfide (species unspecified)	ZnS	Desborough et al. (1976)
Wurtzite	ZnS	Smith & Milton (1966)
Marcasite (2°)	FeS_2	Robb et al. (1978)
Halides		
Cryolite	Na_3AlF_6	Robb et al. (1978) Milton (1977) Desborough et al. (1976) Smith & Milton (1966)
Fluorite	CaF_2	Desborough et al. (1976) Robb & Smith (1974) Smith & Milton (1966) Robb et al. (1978) Fox & Smith (1981)
Halite	NaCl	Dyni (1974) Smith & Milton (1966) Robb et al. (1978)
Oxides		
Quartz	SiO_2	ub
Chalcedony	SiO_2	ub
Hydroxides		
Nordstrandite	$Al(OH)_3$	Milton et al. (1975)

TABLE 68 (cont.)

Mineral	Formula	Reference
Carbonates		
Nahcolite	$NaHCO_3$	Ertl (1947)
		Milton & Eugster (1959)
		Desborough et al. (1976)
		Robb & Smith (1974)
		Beard et al. (1974)
		Dyni (1974)
		Robb et al. (1978)
		Dean et al. (1981)
Shortite	$Na_2Ca_2(CO_3)_3$	Brobst & Tucker (1973)
Wegscheiderite	$Na_5(CO_3)(HCO_3)_3$	Brobst & Tucker (1973)
		Milton (1977)
		Fahey & Yorks (1963)
Calcite	$CaCO_3$	ub
Magnesite	$MgCO_3$	Robb et al. (1978)
		Robb & Smith (1974)
Siderite	$FeCO_3$	Desborough & Pitman (1974)
		Desborough et al. (1976)
		Robb et al. (1978)
		Dean et al. (1981)
		Fox & Smith (1981)
Aragonite	$CaCO_3$	Desborough & Pitman (1974)
		Robb & Smith (1974)
		Robb et al. (1978)
		Smith & Robb (1973)
		Dean et al. (1981)
		Fox & Smith (1981)
Ankerite	$Ca(Fe,Mg,Mn)(CO_3)_2$	Desborough & Pitman (1974)
Dolomite	$CaMg(CO_3)_2$	ub
Dawsonite	$NaAl(CO_3)(OH)_2$	ub
Barytocalcite	$BaCa(CO_3)_2$	Smith & Milton (1966)
		Robb et al. (1978)
Northupite	$Na_3Mg(CO_3)_2Cl$	Robb et al. (1978)

TABLE 68 (cont.)

Mineral	Formula	Reference
Burkerite	$Na_6(CO_3)(SO_4)_2$	Milton (1972)
Norsethite	$BaMg(CO_3)_2$	Robb et al. (1978)
Silicates		
Kaolinite	$Al_2Si_2O_5(OH)_4$	Robb et al. (1978)
Illite	$(K,H_3O)(Al,Mg,Fe)_2(Al,Si)_4O_{10}[(OH)_2 \cdot H_2O]$	Robb & Smith (1974)
		Brobst & Tucker (1973)
		Smith & Milton (1966)
		Saether et al. (1981)
		Robb et al. (1978)
		Smith & Robb (1973)
		Dean et al. (1981)
		Fox & Smith (1981)
Chlorite	$M_{5-6}(Al,Si)_4O_{10}(OH)_8$	Brobst & Tucker (1973)
	M=Mg,Fe,Ni,Mn,Al,Cr,Si	Robb et al. (1978)
Biotite	$K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$	Brobst & Tucker (1973)
Montmorillonite	$(Na,Ca)_{.33}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$	Trudell et al. (1970)
Halloysite	$Al_2Si_2O_5(OH)_4$	Robb et al. (1978)
Orthoclase	$KAlSi_3O_8$	ub
Albite	$NaAlSi_3O_8$	ub
Searlsite	$NaBSi_2O_6 \cdot H_2O$	Smith & Milton (1966)
		Robb et al. (1978)
Acmite	$NaFeSi_2O_6$	Smith & Milton (1966)
Analcime	$NaAlSi_2O_6 \cdot H_2O$	ub
Harmotome-Wellsite	$(Ba,Ca,K_2)Al_2Si_6O_{10} \cdot 6H_2O$	Milton (1977)
Natrolite	$Na_2(Al_2Si_3)O_{10} \cdot 2H_2O$	Pabst (1971)
Sulfites		
Barite	$BaSO_4$	Milton (1977)
		Milton & Eugster (1959)
Gypsum (2°)	$CaSO_4 \cdot 2H_2O$	Brobst & Tucker (1973)
Starkeyite (2°)	$MgSO_4 \cdot 4H_2O$	Brobst & Tucker (1973)

TABLE 68 (cont.)

Mineral	Formula	Reference
Bloedite (2°)	$Na_2Mg(SO_4)_2 \cdot 4H_2O$	Brobst & Tucker (1973)
Szomolnokite (2°)	$FeSO_4 \cdot H_2O$	Brobst & Tucker (1973)
Phosphates		
Apatite	$Ca_5(PO_4)_3(F,Cl,OH)$	Robb & Smith (1974) Robb et al. (1978)
Organics		
Gilsonite		Hunt et al. (1954)
Uintahite		Hunt et al. (1954)
Utahite		Hunt et al. (1954)
Tabbyite		Hunt et al. (1954)
Ozokerite		Morrow (1957)
Ingramite		Hunt et al. (1954)
Abertite		Hunt et al. (1954)
Kerogen		Hunt et al. (1954)

SECTION 3
WATER CHEMISTRY TABLES

TABLE 59. WELL SITES WITH WATER QUALITY DATA TRACT C-B
PERIOD COVERING 10/74 to 5/80

WELL ID	LATITUDE	LONGITUDE	AQUIFER DESIGNATION
WX02	39.8156	108.2061	Upper
WX04	39.7864	108.2011	Upper
WX10	39.7961	108.2183	Upper
WX12	39.8144	108.2433	Upper
WX17	39.7828	108.1808	Upper
WX18	39.7553	108.2189	Upper
WX19	39.8253	108.1997	Upper
WX20	39.8258	108.2067	Upper
WX21	39.8158	108.2233	Upper
WX44	39.8003	108.2122	Upper
WX55	39.7967	108.2019	Upper
WX63	39.8036	108.2089	Upper
WX82	39.8036	108.2089	Upper
WX92	39.7967	108.2389	Upper
WY01	39.8144	108.2342	Lower
WY09	39.7961	108.2183	Lower
WY10	39.7961	108.2183	Lower
WY12	39.8144	108.2433	Lower
WY17	39.7828	108.1808	Lower
WY18	39.7828	108.1808	Lower
WY45	39.8003	108.2122	Lower
WY46	39.8003	108.2122	Lower
WY51	39.7967	108.2019	Lower
WY52	39.7967	108.2019	Lower
WY54	39.7967	108.2019	Lower
WY61	39.8036	108.2089	Lower
WY62	39.8036	108.2089	Lower
WY80	39.8033	108.1733	Lower
WY81	39.8033	108.1733	Lower
WY91	39.7967	108.2389	Lower

TABLE 70. SUMMARY OF CHEMICAL ANALYSES OF WELL WX04, UPPER AQUIFER PERFORMED OCTOBER, 1975

Concentration in MG/L Except Where Noted

Analyte	Results
Alkalinity	NT[A]
Aluminum	0.5
Arsenic	0.005
Fecal Coliforms	NT
Barium	0.03
Bicarbonate	340 (as $CaCO_3$)
Bio. Oxygen Demand	NT
Boron	0.10
Bromide	0.05
Total Coliforms	NT
Cadmium	<0.02
Calcium	20.0
Carbonate	10.0 (as $CaCO_3$)
Chloride	7.0
Chromium	<0.01
Chemical Oxygen Demand	NT
Copper	0.007
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	0.3
Hardness (Ca+Mg)	190 (as $CaCO_3$)
Iron	0.07
Kjeldahl Nitrogen	NT
Lead	0.02
Lithium	<0.5
Magnesium	27.0
Manganese	0.04
Mercury	<0.0001

A) NT = Not Tested For.

TABLE 70 (Continued)

Analyte	Results
Molybdenum	NT
Nickel	0.02
Nitrate	0.8
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.8
Potassium	1.0
Radioactivity-alpha	5.0 PCI/L
Radioactivity-Beta	NT
Radioactivity-Radium-226	NT
Selenium	0.001
Silver	NT
Sodium	140.0
Total Dissolved Solids	540.0
Soluble Solids	NT
Conductivity	800.0
Strontium	5.0
Sulfate	140.0
Temperature	NT
Zinc	0.04
Total Organic Carbon	1.0
Phenols	NT
Cyanide	<0.1
Ammonia as N	0.6
Phosphate	0.1
Silica	20.0
Uranium	0.002
Suspended Solids	NT
Thorium	<0.1
Cesium	0.001
Iodine	0.004

TABLE 70 (Continued)

Analyte	Results
Antimony	<0.1
Zirconium	<0.1
Yttrium	<0.1
Rubidium	0.003
Germanium	<0.1
Gallium	0.001
Titanium	0.2
Scandium	0.001
Tungsten	<0.1
Cobalt	0.001
Vanadium	0.001
Beryllium	<0.1
Hydroxides	NT
Cond. Hydrocarbons	0.1
P. Alkalinity	15
M.O. Alkalinity	390

TABLE 71. SUMMARY OF CHEMICAL ANALYSES FOR WELL WX10, UPPER AQUIFER, PERFORMED APRIL, 1975

Analyte	Results
Alkalinity	NT
Aluminum	0.06
Arsenic	0.006
Fecal Coliforms	NT
Barium	0.02
Bicarbonate	440.0 (as $CaCO_3$)
Bio. Oxygen Demand	NT
Boron	3.20
Bromide	0.02
Total Coliforms	NT
Cadmium	NT
Calcium	57.0
Carbonate	12.0
Chloride	13.0
Chromium	<0.1
Chemical Oxygen Demand	NT
Copper	0.005
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	0.40
Hardness (Ca+Mg)	370 (as $CaCO_3$)
Iron	0.08
Kjeldahl Nitrogen	NT
Lead	<0.01
Lithium	<0.5
Magnesium	50.0
Manganese	0.03
Mercury	<0.0001
Molybdenum	0.04

TABLE 71 (Continued)

Analyte	Results
Nickel	<0.02
Nitrate	0.1
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.6
Potassium	1.0
Radioactivity-alpha	6.0
Radioactivity-beta	NT
Radioactivity-Radium-226	NT
Selenium	0.007
Silver	NT
Sodium	180.0
Total Dissolved Solids	940.0
Soluble Solids	NT
Conductivity	1300.0
Strontium	4.0
Sulfate	380.0
Temperature	NT
Zinc	0.3
Total OR. Carbon	1.0
Phenols	NT
Cyanide	<0.1
Ammonia as N	1.7
Phosphate	0.1
Silica	24.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.002
Iodine	0.002
Antimony	<0.1

TABLE 71 (Continued)

Analyte	Results
Zirconium	0.002
Yttrium	<0.1
Rubidium	0.003
Germanium	<0.1
Gallium	0.002
Titanium	0.03
Scandium	0.005
Tungsten	<0.1
Cobalt	0.002
Vanadium	0.002
Beryllium	<0.1
Hydroxides	NT
Cond. Hydrocarbons	0.1
P. Alkalinity	10.0 (As $CaCO_3$)
M.O. Alkalinity	360.0 (As $CaCO_3$)

TABLE 72. SUMMARY OF CHEMICAL ANALYSES FOR WELL WX12, UPPER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.02
Arsenic	0.09
Fecal Coliforms	NT
Barium	0.06
Bicarbonate	539.0 (As $CaCO_3$)
Bio. Oxygen Demand	NT
Boron	0.3
Bromide	0.009
Total Coliforms	NT
Cadmium	0.02
Calcium	27.0
Carbonate	11.0 (As $CaCO_3$)
Chloride	8.0
Chromium	0.004
Chemical Oxygen Demand	NT
Copper	0.02
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	3.00
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	0.007
Lithium	<0.5
Magnesium	53.0
Manganese	<0.1
Mercury	0.0029
Molybdenum	0.03

TABLE 72 (Continued)

Analyte	Results
Nickel	<0.02
Nitrate	0.1
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.6
Potassium	0.7
Radioactivity-alpha	3.9
Radioactivity-beta	8.0
Radioactivity-Radium-226	NT
Selenium	<0.02
Silver	0.02
Sodium	204.0
Total Dissolved Solids	834.0
Soluble Solids	NT
Conductivity	1347.0
Strontium	3.3
Sulfate	239.0
Temperature	NT
Zinc	0.07
Total Organic Carbon	<0.1
Phenols	NT
Cvanide	<0.1
Ammonia as N	0.37
Phosphate	0.02
Silica	20.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.01
Iodine	0.003
Antimony	<0.1

TABLE 72 (Continued)

Analyte	Results
Zirconium	0.001
Yttrium	<0.1
Rubidium	0.01
Germanium	0.002
Gallium	0.001
Titanium	0.05
Scandium	0.003
Tungsten	<0.1
Cobalt	0.002
Vanadium	0.001
Beryllium	<0.1
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 73. SUMMARY OF CHEMICAL ANALYSES FOR WELL WX17, UPPER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.06
Arsenic	0.008
Fecal Coliforms	NT
Barium	0.10
Bicarbonate	883 (As $CaCO_3$)
Bio. Oxygen Demand	NT
Boron	0.30
Bromide	0.01
Total Coliforms	NT
Cadmium	NT
Calcium	9.0
Carbonate	28.0
Chloride	20.0
Chromium	0.007
Chemical Oxygen Demand	NT
Copper	0.007
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	17.0
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	0.008
Lithium	<0.5
Magnesium	3.0
Manganese	<0.1
Mercury	0.00008
Molybdenum	0.006

TABLE 73 (Continued)

Analyte	Results
Nickel	0.006
Nitrate	0.06
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.9
Potassium	1.7
Radioactivity-alpha	2.4
Radioactivity-beta	NT
Radioactivity-Radium-226	NT
Selenium	0.001
Silver	0.002
Sodium	330.0
Total Dissolved Solids	941.0
Soluble Solids	NT
Conductivity	1661.0
Strontium	0.2
Sulfate	21.0
Temperature	NT
Zinc	0.02
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	0.43
Phosphate	0.03
Silica	13.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.01
Iodine	0.002
Antimony	<0.1

TABLE 73 (Continued)

Analyte	Results
Zirconium	<0.1
Yttrium	<0.1
Rubidium	0.008
Germanium	0.001
Gallium	0.001
Titanium	0.04
Scandium	0.001
Tungsten	<0.1
Cobalt	0.004
Vanadium	0.001
Beryllium	0.001
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 74. SUMMARY OF CHEMICAL ANALYSES ON WELL WX19, UPPER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.003
Arsenic	0.001
Fecal Coliforms	NT
Barium	0.3
Bicarbonate	1780
Bio. Oxygen Demand	NT
Boron	0.2
Bromide	0.006
Total Coliforms	NT
Cadmium	NT
Calcium	5.0
Carbonate	42.0
Chloride	12.0
Chromium	0.002
Chemical Oxygen Demand	NT
Copper	0.008
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	23.0
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	0.004
Lithium	<0.5
Magnesium	3.0
Manganese	<0.1
Mercury	0.00009
Molybdenum	0.003

TABLE 74 (Continued)

Analyte	Results
Nickel	<0.02
Nitrate	0.03
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.8
Potassium	0.9
Radioactivity-alpha	NT
Radioactivity-beta	NT
Radioactivity-Radium-226	NT
Selenium	0.001
Silver	NT
Sodium	760.0
Total Dissolved Solids	1741.0
Soluble Solids	NT
Conductivity	2864.0
Strontium	0.4
Sulfate	4.0
Temperature	NT
Zinc	0.01
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	1.2
Phosphate	0.03
Silica	13.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.002
Iodine	0.002
Antimony	<0.1

TABLE 74 (Continued)

Analyte	Results
Zirconium	0.001
Yttrium	<0.1
Rubidium	0.004
Germanium	0.001
Gallium	0.001
Titanium	0.02
Scandium	0.002
Tungsten	<0.1
Cobalt	0.002
Vanadium	0.001
Beryllium	0.001
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 75. SUMMARY OF CHEMICAL ANALYSES FOR WELL WX20, UPPER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.02
Arsenic	0.002
Fecal Coliforms	NT
Barium	<0.5
Bicarbonate	1780.0
Bio. Oxygen Demand	NT
Boron	3.00
Bromide	0.006
Total Coliforms	NT
Cadmium	NT
Calcium	5.0
Carbonate	42.0
Chloride	12.0
Chromium	0.005
Chemical Oxygen Demand	NT
Copper	0.03
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	21.0
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	0.02
Lithium	<0.5
Magnesium	3.0
Manganese	<0.1
Mercury	0.00008
Molybdenum	NT
Nickel	0.007

TABLE 75 (Continued)

Analyte	Results
Nitrate	2.90
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.8
Potassium	0.9
Radioactivity-alpha	2.2
Radioactivity-beta	NT
Radioactivity-Radium-226	NT
Selenium	0.003
Silver	NT
Sodium	737.0
Total Dissolved Solids	1715.0
Soluble Solids	NT
Conductivity	2845.0
Strontium	0.5
Sulfate	5.0
Temperature	NT
Zinc	0.008
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	0.6
Phosphate	0.03
Silica	11.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.005
Iodine	0.004
Antimony	<0.1
Zirconium	<0.1

TABLE 75 (Continued)

Analyte	Results
Yttrium	<0.1
Rubidium	0.008
Germanium	<0.1
Gallium	0.004
Titanium	0.06
Scandium	0.004
Tungsten	<0.1
Cobalt	0.01
Vanadium	0.002
Beryllium	0.001
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 76. SUMMARY OF CHEMICAL ANALYSES FOR WELL WX44, UPPER AQUIFER, PERFORMED MAY, 1976

Analyte	Results
Alkalinity	NT
Aluminum	NT
Arsenic	0.013
Fecal Coliforms	NT
Barium	NT
Bicarbonate	451.0
Bio. Oxygen Demand	NT
Boron	NT
Bromide	NT
Total Coliforms	NT
Cadmium	NT
Calcium	52.0
Carbonate	3.3
Chloride	9.0
Chromium	NT
Chemical Oxygen Demand	NT
Copper	NT
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	3.10
Hardness (Ca+Mg)	NT
Iron	1.1
Kjeldahl Nitrogen	NT
Lead	NT
Lithium	NT
Magnesium	50.0
Manganese	0.2
Mercury	NT
Molybdenum	0.02
Nickel	NT

TABLE 76 (Continued)

Analyte	Results
Yttrium	<0.1
Rubidium	<0.1
Germanium	<0.1
Gallium	<0.1
Titanium	<0.1
Scandium	<0.1
Tungsten	<0.1
Cobalt	0.1
Vanadium	<0.1
Beryllium	<0.1
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 77. SUMMARY OF CHEMICAL ANALYSES FOR WELL WX92, UPPER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.03
Arsenic	0.02
Fecal Coliforms	NT
Barium	0.03
Bicarbonate	677.0
Bio. Oxygen Demand	NT
Boron	0.07
Bromide	<0.1
Total Coliforms	NT
Cadmium	<0.02
Calcium	92.0
Carbonate	6.0
Chloride	17.0
Chromium	0.02
Chemical Oxygen Demand	NT
Copper	<0.02
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	2.40
Hardness (Ca+Mg)	NT
Iron	7.0
Kjeldahl Nitrogen	NT
Lead	<0.01
Lithium	<0.5
Magnesium	133.0
Manganese	0.3
Mercury	0.00009
Molybdenum	0.02
Nickel	0.03

TABLE 77 (Continued)

Analyte	Results
Nitrate	0.08
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.3
Potassium	2.0
Radioactivity-alpha	0.7
Radioactivity-beta	NT
Radioactivity-Radium-226	NT
Selenium	0.03
Silver	NT
Sodium	195.0
Total Dissolved Solids	1318.0
Soluble Solids	NT
Conductivity	1822.0
Strontium	4.0
Sulfate	497.0
Temperature	NT
Zinc	0.03
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	0.32
Phosphate	0.02
Silica	30.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.002
Iodine	0.003
Antimony	<0.1
Zirconium	<0.1

TABLE 77 (Continued)

Analyte	Results
Yttrium	<0.1
Rubidium	0.01
Germanium	<0.1
Gallium	0.003
Titanium	0.08
Scandium	0.005
Tungsten	<0.1
Cobalt	0.007
Vanadium	0.001
Beryllium	<0.1
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 78. SUMMARY OF CHEMICAL ANALYSES FOR WELL WY01,
LOWER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.6
Arsenic	0.004
Fecal Coliforms	NT
Barium	<0.5
Bicarbonate	2670.0
Bio. Oxygen Demand	NT
Boron	1.0
Bromide	0.01
Total Coliforms	NT
Cadmium	<0.02
Calcium	4.0
Carbonate	55.0
Chloride	17.0
Chromium	0.004
Chemical Oxygen Demand	NT
Copper	0.03
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	28.0
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	0.008
Lithium	<0.5
Magnesium	3.0
Manganese	<0.1
Mercury	0.00007
Molybdenum	0.005
Nickel	NT

TABLE 78 (Continued)

Analyte	Results
Nitrate	0.02
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.7
Potassium	5.0
Radioactivity-alpha	19.0
Radioactivity-beta	NT
Radioactivity-Radium-226	NT
Selenium	0.002
Silver	NT
Sodium	1120.0
Total Dissolved Solids	2570.0
Soluble Solids	NT
Conductivity	4097.0
Strontium	0.4
Sulfate	10.0
Temperature	NT
Zinc	0.01
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	2.2
Phosphate	0.04
Silica	17.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.01
Iodine	0.002
Antimony	<0.1
Zirconium	0.002

TABLE 78 (Continued)

Analyte	Results
Yttrium	0.001
Rubidium	0.02
Germanium	0.002
Gallium	0.001
Titanium	0.05
Scandium	0.003
Tungsten	<0.1
Cobalt	0.004
Vanadium	0.001
Beryllium	0.001
Hydroxides	<0.1
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 79. SUMMARY OF CHEMICAL ANALYSES FOR WELL WY12, LOWER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	0.0
Aluminum	0.06
Arsenic	0.06
Fecal Coliforms	NT
Barium	0.02
Bicarbonate	4300.0
Bio. Oxygen Demand	NT
Boron	NT
Bromide	0.08
Total Coliforms	NT
Cadmium	NT
Calcium	7.0
Carbonate	120.0
Chloride	700.0
Chromium	0.002
Chemical Oxygen Demand	NT
Copper	0.02
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	25.0
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	0.03
Lithium	5.0
Magnesium	10.0
Manganese	<0.1
Mercury	0.00009
Molybdenum	0.02
Nickel	NT

TABLE 79 (Continued)

Analyte	Results
Nitrate	0.28
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.7
Potassium	20.0
Radioactivity-alpha	33.0
Radioactivity-beta	NT
Radioactivity-Radium-226	NT
Selenium	0.008
Silver	NT
Sodium	2320.0
Total Dissolved Solids	5747.0
Soluble Solids	NT
Conductivity	8369.0
Strontium	0.2
Sulfate	313.0
Temperature	NT
Zinc	0.009
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	15.5
Phosphate	0.02
Silica	17.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.01
Iodine	0.06
Antimony	0.01
Zirconium	0.01

TABLE 79 (Continued)

Analyte	Results
Yttrium	0.02
Rubidium	0.01
Germanium	0.02
Gallium	0.01
Titanium	0.08
Scandium	0.01
Tungsten	0.02
Cobalt	0.01
Vanadium	0.006
Beryllium	<0.1
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 80. SUMMARY OF CHEMICAL ANALYSES FOR WELL WY17, LOWER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.09
Arsenic	0.02
Fecal Coliforms	NT
Barium	0.7
Bicarbonate	3260.0
Bio. Oxygen Demand	NT
Boron	9.0
Bromide	0.3
Total Coliforms	NT
Cadmium	NT
Calcium	10.0
Carbonate	108.0
Chloride	640.0
Chromium	0.005
Chemical Oxygen Demand	NT
Copper	0.03
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	21.0
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	0.02
Lithium	2.6
Magnesium	7.0
Manganese	<0.1
Mercury	0.00009
Molybdenum	NT
Nickel	NT

TABLE 80 (Continued)

Analyte	Results
Nitrate	0.02
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.7
Potassium	11.0
Radioactivity-alpha	17.0
Radioactivity-beta	2.0
Radioactivity-Radium-226	NT
Selenium	0.003
Silver	NT
Sodium	1800.0
Total Dissolved Solids	4300.0
Soluble Solids	NT
Conductivity	6768.0
Strontium	0.6
Sulfate	7.0
Temperature	NT
Zinc	0.005
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	12.0
Phosphate	0.04
Silica	17.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.005
Iodine	0.05
Antimony	<0.1
Zirconium	0.003

TABLE 80 (Continued)

Analyte	Results
Yttrium	<0.1
Rubidium	0.01
Germanium	<0.1
Gallium	0.004
Titanium	0.2
Scandium	0.008
Tungsten	<0.1
Cobalt	0.002
Vanadium	0.001
Beryllium	0.001
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 81. SUMMARY OF CHEMICAL ANALYSES FOR WELL WY45, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	1.0
Arsenic	0.02
Fecal Coliforms	NT
Barium	0.1
Bicarbonate	738.0
Bio. Oxygen Demand	NT
Boron	0.05
Bromide	0.01
Total Coliforms	NT
Cadmium	NT
Calcium	5.0
Carbonate	30.0
Chloride	9.0
Chromium	<0.01
Chemical Oxygen Demand	NT
Copper	0.2
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	20.0
Hardness (Ca+Mg)	NT
Iron	6.0
Kjeldahl Nitrogen	NT
ead	0.1
Lithium	<0.5
Magnesium	3.0
Manganese	<0.1
Mercury	0.00004
Molybdenum	0.008
Nickel	0.02

TABLE 81 (Continued)

Analyte	Results
Nitrate	0.08
Oil and Grease	NT
Thiosulfate	<0.1
pH	9.0
Potassium	10.0
Radioactivity-alpha	18.0
Radioactivity-beta	33.0
Radioactivity-Radium-226	NT
Selenium	0.004
Silver	NT
Sodium	340.0
Total Dissolved Solids	817.0
Soluble Solids	NT
Conductivity	1415.0
Strontium	0.3
Sulfate	17.0
Temperature	NT
Zinc	0.04
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	0.6
Phosphate	0.03
Silica	12.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.01
Iodine	0.002
Antimony	0.04
Zirconium	0.003

TABLE 81 (Continued)

Analyte	Results
Yttrium	<0.1
Rubidium	0.04
Germanium	<0.1
Gallium	0.003
Titanium	0.01
Scandium	0.007
Tungsten	<0.1
Cobalt	0.009
Vanadium	0.001
Beryllium	<0.1
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 82. SUMMARY OF CHEMICAL ANALYSES FOR WELL WY46, LOWER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.04
Arsenic	0.007
Fecal Coliforms	NT
Barium	0.10
Bicarbonate	722.0
Bio. Oxygen Demand	NT
Boron	0.1
Bromide	0.004
Total Coliforms	NT
Cadmium	NT
Calcium	6.0
Carbonate	14.0
Chloride	3.0
Chromium	0.009
Chemical Oxygen Demand	NT
Copper	0.004
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	17.0
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	<0.01
Lithium	<0.5
Magnesium	4.0
Manganese	<0.1
Mercury	0.00007
Molybdenum	0.008
Nickel	0.003

TABLE 82 (Continued)

Analyte	Results
Nitrate	0.22
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.7
Potassium	2.0
Radioactivity-alpha	8.5
Radioactivity-beta	24.0
Radioactivity-Radium-226	NT
Selenium	0.002
Silver	NT
Sodium	310.0
Total Dissolved Solids	748.0
Soluble Solids	NT
Conductivity	1329.0
Strontium	0.6
Sulfate	22.0
Temperature	NT
Zinc	0.01
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	0.36
Phosphate	0.03
Silica	14.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.008
Iodine	0.002
Antimony	<0.1
Zirconium	0.002

TABLE 82 (Continued)

Analyte	Results
Yttrium	<0.1
Rubidium	0.007
Germanium	<0.1
Gallium	0.003
Titanium	0.03
Scandium	0.001
Tungsten	<0.1
Cobalt	0.007
Vanadium	0.001
Beryllium	<0.1
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 83. SUMMARY OF CHEMICAL ANALYSES FOR WELL WY52, LOWER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.04
Arsenic	0.04
Fecal Coliforms	NT
Barium	6.0
Bicarbonate	11,300
Bio. Oxygen Demand	NT
Boron	NT
Bromide	0.6
Total Coliforms	NT
Cadmium	NT
Calcium	9.0
Carbonate	288.0
Chloride	3280.0
Chromium	0.007
Chemical Oxygen Demand	NT
Copper	0.01
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	26.0
Hardness (Ca+Mg)	NT
Iron	1.8
Kjeldahl Nitrogen	NT
Lead	0.03
Lithium	23.0
Magnesium	8.0
Manganese	<0.1
Mercury	0.00023
Molybdenum	NT

TABLE 83 (Continued)

Analyte	Results
Nickel	NT
Nitrate	0.06
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.6
Potassium	34.0
Radioactivity-alpha	NT
Radioactivity-beta	70.0
Radioactivity-Radium-226	NT
Selenium	NT
Silver	0.01
Sodium	6140
Total Dissolved Solids	15870.0
Soluble Solids	NT
Conductivity	20420.0
Strontium	1.2
Sulfate	20.0
Temperature	NT
Zinc	0.03
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	25.5
Phosphate	0.24
Silica	19.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.04
Iodine	0.08
Antimony	0.01

TABLE 83 (Continued)

Analyte	Results
Zirconium	0.1
Yttrium	0.03
Rubidium	0.2
Germanium	<0.1
Gallium	0.007
Titanium	0.1
Scandium	0.01
Tungsten	<0.1
Cobalt	0.02
Vanadium	0.03
Beryllium	0.001
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 84. SUMMARY OF CHEMICAL ANALYSES FOR WELL WY52, LOWER AQUIFER, PERFORMED DECEMBER, 1979

Analyte	Results
Alkalinity	1400.0
Aluminum	<0.1
Arsenic	<0.02
Fecal Coliforms	NT
Barium	5.0
Bicarbonate	1300
Bio. Oxygen Demand	11.0
Boron	9.0
Bromide	<0.1
Total Coliforms	NT
Cadmium	NT
Calcium	6.8
Carbonate	150.0
Chloride	20.0
Chromium	0.02
Chemical Oxygen Demand	9.0
Copper	<0.02
Dissolved Oxygen	NT
Dissolved Organic Carbon	8.6
Surfactants	NT
Fluoride	20.0
Hardness (Ca+Mg)	29.0
Iron	<0.02
Kjeldahl Nitrogen	5.0
Lead	<0.02
Lithium	1.4
Magnesium	3.0
Manganese	0.04
Mercury	<0.02
Molybdenum	0.03

TABLE 84 (Continued)

Analyte	Results
Nickel	<0.02
Nitrate	18.0
Oil and Grease	10.0
Thiosulfate	NT
pH	NT
Potassium	3.7
Radioactivity-alpha	5.3
Radioactivity-beta	22.0
Radioactivity-Radium-226	NT
Selenium	<0.02
Silver	<0.01
Sodium	650.0
Total Dissolved Solids	1900.0
Soluble Solids	NT
Conductivity	NT
Strontium	1.7
Sulfate	7.0
Temperature	NT
Zinc	<0.02
Total Organic Carbon	NT
Phenols	<0.001
Cyanide	NT
Ammonia as N	5.5
Phosphate	NT
Silica	NT
Uranium	NT
Suspended Solids	NT
Thorium	NT
Cesium	NT
Iodine	NT
Antimony	NT
Zirconium	NT

TABLE 84 (Continued)

Analyte	Results
Yttrium	NT
Rubidium	NT
Germanium	NT
Gallium	NT
Titanium	NT
Scandium	NT
Tungsten	NT
Cobalt	0.02
Vanadium	NT
Beryllium	NT
Hydroxides	NT
Cond. Hydrocarbons	NT
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 85. SUMMARY OF CHEMICAL ANALYSES FOR WELL WY61, LOWER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.1
Arsenic	0.009
Fecal Coliforms	NT
Barium	0.2
Bicarbonate	1860.0
Bio. Oxygen Demand	NT
Boron	0.7
Bromide	0.01
Total Coliforms	NT
Cadmium	NT
Calcium	7.0
Carbonate	47.0
Chloride	50.0
Chromium	0.005
Chemical Oxygen Demand	NT
Copper	0.04
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	22.0
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	0.004
Lithium	0.5
Magnesium	4.0
Manganese	<0.1
Mercury	0.00008
Molybdenum	0.02

TABLE 85 (Continued)

Analyte	Results
Nickel	NT
Nitrate	0.24
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.8
Potassium	6.0
Radioactivity-alpha	6.2
Radioactivity-beta	33.0
Radioactivity-Radium-226	NT
Selenium	0.001
Silver	NT
Sodium	800.0
Total Dissolved Solids	1894.0
Soluble Solids	NT
Conductivity	3099.0
Strontium	0.2
Sulfate	26.0
Temperature	NT
Zinc	0.02
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	2.2
Phosphate	0.07
Silica	15.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.003
Iodine	0.001
Antimony	<0.1

TABLE 85 (Continued)

Analyte	Results
Zirconium	0.001
Yttrium	<0.1
Rubidium	0.009
Germanium	0.001
Gallium	0.001
Titanium	1.0
Scandium	0.004
Tungsten	<0.1
Cobalt	0.002
Vanadium	0.001
Beryllium	0.001
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Aikalinity	NT
M.O. Alkalinity	NT

TABLE 86. SUMMARY OF CHEMICAL ANALYSES FOR WELL WY62, LOWER AQUIFER, PERFORMED OCTOBER, 1976

Analyte	Results
Alkalinity	NT
Aluminum	0.03
Arsenic	0.001
Fecal Coliforms	NT
Barium	0.02
Bicarbonate	744.0
Bio. Oxygen Demand	NT
Boron	0.30
Bromide	0.003
Total Coliforms	NT
Cadmium	NT
Calcium	5.0
Carbonate	20.0
Chloride	12.0
Chromium	0.007
Chemical Oxygen Demand	NT
Copper	<0.02
Dissolved Oxygen	0.1
Dissolved Organic Carbon	<0.1
Surfactants	<0.1
Fluoride	17.0
Hardness (Ca+Mg)	NT
Iron	<0.1
Kjeldahl Nitrogen	NT
Lead	<0.01
Lithium	<0.5
Magnesium	4.0
Manganese	<0.1
Mercury	0.00015
Molybdenum	0.02

TABLE 86 (Continued)

Analyte	Results
Nickel	<0.02
Nitrate	0.16
Oil and Grease	NT
Thiosulfate	<0.1
pH	8.9
Potassium	2.0
Radioactivity-alpha	4.4
Radioactivity-beta	NT
Radioactivity-Radium-226	NT
Selenium	0.004
Silver	NT
Sodium	320
Total Dissolved Solids	776
Soluble Solids	NT
Conductivity	2211.0
Strontium	0.3
Sulfate	17.0
Temperature	NT
Zinc	NT
Total Organic Carbon	<0.1
Phenols	NT
Cyanide	<0.1
Ammonia as N	0.76
Phosphate	0.02
Silica	11.0
Uranium	<0.1
Suspended Solids	NT
Thorium	<0.1
Cesium	0.005
Iodine	0.002
Antimony	<0.1

TABLE 36 (Continued)

Analyte	Results
Zirconium	0.002
Yttrium	<0.1
Rubidium	0.005
Germanium	<0.1
Gallium	0.002
Titanium	0.03
Scandium	0.005
Tungsten	<0.1
Cobalt	0.006
Vanadium	0.001
Beryllium	<0.1
Hydroxides	NT
Cond. Hydrocarbons	<0.1
P. Alkalinity	NT
M.O. Alkalinity	NT

TABLE 87. CONCENTRATIONS (MG/L) OF SELECTED SPECIES FOR WELL ANALYSES FROM TABLES 2-18

Well ID	TDS	Na^+	Ca^{++}	Mg++	K+	SO_4^{--}	Cl^-	HCO_3^-	CO_3^{--}	F^-	SiO_2	Sr
WX04	540	140	20	27	1.0	140	7	340	10	0.3	20	5
WX10	940	180	57	50	1.0	380	13	440	12	0.4	24	4
WX12	834	204	27	53	0.7	239	8	539	11	3	20	3.3
WX17	941	330	9	3	1.7	21	20	883	28	17	13	0.2
WX19	1741	760	5	3	0.9	4	12	1700	42	23	13	0.4
WX20	1715	737	5	3	0.9	5	12	1780	42	21	11	0.5
WX44	935	200	52	50	2.6	370	9	451	3.3	3.1	19	3.6
WX92	1318	195	92	133	2.0	497	17	677	6	2.4	30	4
WY01	2570	1120	4	3	5	10	17	2670	55	28	17	0.4
WY12	5747	2320	7	10	20	313	700	4300	120	25	17	0.2
WY17	4300	1800	10	7	11	7	640	3260	108	21	17	0.6
WY45	817	340	5	3	10	17	9	738	30	20	12	0.3
WY46	748	310	6	2	4	22	3	722	14	17	14	0.6
WY52 Oct. '75	15870	6140	9	8	34	20	3280	11300	288	26	19	1.2
WY52 Dec. '79	1900	650	6.8	3	3.7	7	20	1300	150	20	--	1.7
WY61	1894	800	7	4	6	26	50	1860	47	22	15	0.2

TABLE 88. SUMMARY OF WET CHEMICAL ANALYSES FOR THE AQUIFERS AT TRACT C-A, JULY 31, 1979

Analyte	Concentration (MG/L) Lower Aquifer	Upper Aquifer
Aluminum	0.12	2.2
Ammonia	0.601	10.6
Arsenic	0.001	0.2
Bicarbonate	1143.1	625.3
Cadmium	0.002	0.002
Calcium	48.9	73.0
Carbonate	97.7	34.4
Chloride	38.0	29.2
Chromium	0.000	0.009
Copper	0.014	0.024
Fluoride	13.3	5.0
Iron	2.3	1.8
Lead	0.29	0.29
Magnesium	39.15	48.3
Mercury	0.000	0.001
Nitrate	0.98	0.46
Phosphate	0.06	0.29
Potassium	26.8	12.8
Selenium	0.0	0.0
Silicon Dioxide	12.7	25.7
Sodium	552.0	274.4
Sulfate	244.5	324.5
Sulfide	1.5	1.6
Zinc	0.5	0.4
pH	7.3	7.1
Conductance	2469.8 MHOS/L	1518.6
Diss. Solids	1682.3	1165.8
Manganese	0.06	0.1
Alkalinity	965.9	530.6
Cyanide	0.0	0.0

TABLE 88 (Continued)

	Concentration (MG/L)	
Analyte	Lower Aquifer	Upper Aquifer
Boron	2.1	0.8
Barium	0.0	0.0
Silver	0.006	0.01
Nickel	0.02	0.02
Lithium	0.0	0.0
TOC	9.2	7.5

TABLE 89. SUMMARY OF SPECTROGRAPHIC ANALYSES FOR AQUIFERS AT TRACT C-A, JULY 31, 1975

Analyte	Concentration (MG/L) Lower Aquifer	Upper Aquifer
Aluminum	0.2	0.2
Antimony	0.0	0.0
Arsenic	0.0	0.0
Barium	0.04	0.02
Berylium	0.0	0.0
Bismuth	0.0	0.0
Boron	0.6	0.4
Cadmium	0.0	0.0
Calcium	8.0	5.5
Cerium	0.0	0.0
Cesium	0.0	0.0
Chromium	0.01	0.01
Cobalt	0.0	0.001
Columbium	0.0	0.0
Copper	0.01	0.01
Dysprosium	0.0	0.0
Erbium	0.0	0.0
Europium	0.0	0.0
Gadolinium	0.0	0.0
Galium	0.0	0.0
Germanium	0.0	0.0
Gold	0.0	0.0
Hafnium	0.0	0.0
Holmium	0.0	0.0
Indium	0.0	0.0
Iridium	0.0	0.0
Iron	0.3	0.1
Lanthanum	0.0	0.0
Lead	0.05	0.1
Lithium	0.2	0.1

TABLE 89 (Continued)

	Concentration (MG/L)	
Analyte	Lower Aquifer	Upper Aquifer
Lutetium	0.0	0.0
Magnesium	5.7	8.0
Manganese	0.02	0.06
Mercury	0.0	0.0
Molybdenum	0.003	0.007
Neodymium	0.0	0.0
Nickel	0.0	0.005
Osmium	0.0	0.0
Paladium	0.0	0.0
Platinum	0.0	0.0
Potassium	2.2	1.4
Praesodymium	0.0	0.0
Radium	0.4	0.2
Rhenium	0.0	0.0
Rhodium	0.0	0.0
Rubidium	0.0	0.0
Ruthenium	0.0	0.0
Samarium	0.0	0.0
Scandium	0.0	0.0
Selenium	0.0	0.0
Silicon	8.0	17.0
Silver	0.001	0.000
Sodium	5.0	5.7
Strontium	0.2	0.2
Tantalum	0.0	0.0
Terbium	0.0	0.0
Thallium	0.0	0.0
Thorium	0.0	0.0
Thulium	0.0	0.0
Tin	0.0	0.0

TABLE 89 (Continued)

Analyte	Concentration (MG/L) Lower Aquifer	Upper Aquifer
Titanium	0.008	0.02
Tungsten	0.0	0.0
Uranium	0.0	0.0
Vanadium	0.0	0.01
Ytterbium	0.0	0.0
Yttrium	0.0	0.0
Zinc	0.1	0.1
Zirconium	0.0	NT

TABLE 90. SUMMARY OF WET CHEMICAL ANALYSES FOR THE AQUIFERS AT TRACT C-A, SEPTEMBER 31, 1975

Analyte	Concentration (MG/L) Lower Aquifer	Upper Aquifer
Aluminum	0.12	0.18
Ammonia	0.56	0.65
Arsenic	0.001	0.004
Bicarbonate	1082.2	607.2
Cadmium	0.001	0.002
Calcium	42.1	69.3
Carbonate	98.5	36.3
Chloride	35.7	26.3
Chromium	0.000	0.006
Copper	0.02	0.03
Fluoride	13.5	4.3
Iron	2.8	3.2
Lead	0.64	0.32
Magnesium	38.0	50.8
Mercury	0.000	0.000
Nitrate	0.8	0.5
Phosphate	0.05	0.21
Potassium	26.8	12.8
Selenium	0.0	0.0
Silicon Dioxide	11.8	25.3
Sodium	534.0	273.0
Sulfate	229.0	331.4
Sulfide	1.5	1.6
Zinc	1.4	0.7
pH	7.76	7.07
Diss. Solids	1589.4	1150.7
Manganese	0.06	0.1
Alkalinity	929.1	515.6
Cyanide	0.0	0.0
Boron	1.76	0.68

TABLE 90 (Continued)

	Concentration (MG/L)	
Analyte	Lower Aquifer	Upper Aquifer
Barium	0.0	0.0
Silver	0.004	0.008
Nickel	0.022	0.026
Lithium	0.0	0.0
TOC	8.85	7.88

TABLE 91. SUMMARY OF SPECTROGRAPHIC ANALYSES FOR THE AQUIFERS AT TRACT C-A, SEPTEMBER 31, 1975

	Concentration (MG/L)	
Analyte	Lower Aquifer	Upper Aquifer
Aluminum	0.2	0.17
Antimony	0.0	0.0
Arsenic	0.0	0.0
Barium	0.04	0.02
Beryllium	0.0	0.0
Bismuth	0.0	0.0
Boron	0.48	0.32
Cadmium	0.0	0.0
Calcium	8.9	5.5
Cerium	0.0	0.0
Cesium	0.0	0.0
Chromium	0.005	0.01
Cobalt	0.0	0.001
Columbium	0.0	0.0
Copper	0.009	0.01
Dysprosium	0.0	0.0
Erbium	0.0	0.0
Europium	0.0	0.0
Gadolinium	0.0	0.0
Gallium	0.0	0.0
Germanium	0.0	0.0
Gold	0.0	0.0
Hafnium	0.0	0.0
Holmium	0.0	0.0
Indium	0.0	0.0
Iridium	0.0	0.0
Iron	0.21	0.12
Lanthanum	0.0	0.0
Lead	0.06	0.06
Lithium	0.12	0.05

TABLE 91 (Continued)

	Concentration (MG/L)	
Analyte	Lower Aquifer	Upper Aquifer
Lutetium	0.0	0.0
Magnesium	5.5	7.0
Manganese	0.03	0.06
Mercury	0.0	0.0
Molybdenum	0.009	0.03
Neodymium	0.0	0.0
Nickel	0.0	0.007
Osmium	0.0	0.0
Paladium	0.0	0.1
Platinum	0.0	0.0
Potassium	1.9	1.4
Praesodymium	0.0	0.0
Radium	0.5	0.2
Rhenium	0.0	0.0
Rhodium	0.0	0.0
Rubidium	0.0	0.0
Ruthenium	0.0	0.0
Samarium	0.0	0.0
Scandium	0.0	0.0
Selenium	0.0	0.0
Silicon	7.6	14.1
Silver	0.001	0.000
Sodium	7.07	8.13
Strontium	0.15	0.18
Tantalum	0.0	0.0
Terbium	0.0	0.0
Thallium	0.0	0.0
Thorium	1.0	0.0
Thulium	0.0	0.0
Tin	0.0	0.0

TABLE 91 (Continued)

	Concentration (MG/L)	
Analyte	Lower Aquifer	Upper Aquifer
Titanium	0.006	0.02
Tungsten	0.0	0.0
Uranium	0.0	0.0
Vanadium	0.0	0.03
Ytterbium	0.0	0.0
Yttrium	0.0	0.0
Zinc	0.09	0.06
Zirconium	0.0	0.0

TABLE 92. LEVELS OF TRACE ELEMENTS IN GREEN RIVER OIL SHALE

Element	Concentration as Reported by LERC (PPM)		Concentration as Reported by DRI (PPM)
	Mahogany Zone	Saline Zone	
Be	2	1	1.3
Hg	0.5	--	0.4
Cd	0.1	0.4	1
Sb	0.4	3	1
Se	3.0	1.5	1.5
Mo	15	30	10
Ni	300	85	25
Pb	3	15	20
As	30	20	35
Cr	400	100	34
Cu	45	30	37
Zr	30	50	40
B	80	50	65
Zn	15	30	70
V	100	80	100
Mn	250	250	250
F	2000	1000	1000

TABLE 93. MAXIMUM AND MINIMUM CONCENTRATIONS OF TRACE ELEMENTS IN SPENT AND FRESH OIL SHALE FROM GULF-STANDARD DRILLING PROGRAM (PPM)

Corehole Number		Cadmium		Antimony		Arsenic		Mercury		Selenium		Fluoride		Boron	
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
GS 1	Fresh	3.45	1.72	0.8	0.2	13.1	4.0	1.92	0.24	0.9	0.2	937	280	516	95
	Spent	3.33	1.46	0.6	0.1	12.3	1.0	1.89	0.19	1.1	0.2	846	64	269	31
GS 2-3	Fresh	3.98	1.67	1.7	0.2	12.0	0.9	4.54	0.21	0.6	0.1	750	75	190	50
	Spent	2.95	1.56	1.0	0.1	9.8	0.7	1.75	<0.01	0.8	0.1	790	75	150	<0.5
GS 4-5	Fresh	3.35	1.65	1.0	0.2	12.0	4.7	0.93	0.22	1.3	0.1	1315	152	311	14
	Spent	3.84	1.94	0.7	0.1	8.2	2.6	0.56	0.17	1.1	0.2	1217	79	185	6
GS 7	Fresh	2.98	1.19	1.1	0.3	8.1	2.5	3.06	0.54	0.8	0.2	1300	140	160	59
	Spent	3.06	1.37	1.2	0.3	7.5	1.1	3.04	0.3	0.9	0.2	1100	140	140	37
GS 9	Fresh	3.43	1.6	1.0	0.2	12.4	4.9	1.23	0.21	0.4	0.1	994	188	243	81
	Spent	3.87	1.85	0.6	0.1	15.7	1.5	1.26	0.05	0.5	0.1	779	84	329	5
GS 10	Fresh	4.02	1.33	1.1	0.2	11.4	4.0	1.18	0.18	0.7	0.1	1068	178	242	39
	Spent	3.17	2.16	0.9	0.2	7.4	2.8	0.48	0.13	0.9	0.1	836	155	215	30
GS 11	Fresh	3.12	0.84	1.2	0.1	11.4	4.2	1.65	0.13	0.9	0.1	968	131	344	88
	Spent	3.13	1.59	0.8	0.1	8.9	3.0	0.42	0.12	1.2	0.1	771	215	240	38
GS 15	Fresh	3.56	1.31	1.3	0.2	15.1	2.2	1.17	0.11	1.0	0.1	1488	366	267	19
	Spent	3.37	1.35	1.2	0.1	12.4	1.0	0.72	0.08	1.0	0.3	1013	155	211	31

TABLE 94. RETORTING VARIABLES EMPLOYED TO CONTROL THE PYROLYSIS OF OIL SHALE

Gaseous Environment

- Air
- Air + Recycle Gas
- Inert Gas (N_2)

Retorting Temperature

- Effective Pyrolysis Occurs at 482°C
- Carbonate Decomposition Begins at 621°C

Retorting Rate

- Rate of Movement of Pyrolysis Zone

Turbulence

- Turbulence within Retort Caused by Flow of Input Gas

Heat Source

- Internal (Combustion)
- External

TABLE 95. ORGANIC OIL SHALE PRODUCTS AND BY-PRODUCTS

Neutral Compounds

N-Alkanes
N-Alkenes
Cyclohexane
Alkyl cyclohexanes
Branched Alkanes
Branched Alkenes
Alkylfurans
Alkylthiophenes
Pristane
Phytane

Aromatic Compounds

Indene
Alkylindenes
Naphthalene
Alkylanisole
Biphenyl
Acenaphthylene
Alkylnaphthalenes
Acenaphthene
Fluorene
Alkylfluorenes
Phenanthrene
Anthracene
Alkylphenanthrenes
Fluoranthene
Pyrene
Chrysene
Methylchrysenes
Cholanthrene
Benzofluoranthenes
Benzophyrenes

Acidic Compounds

Alkylphenols
Naphthol
Alkylnaphthols
Thionaphthols
Thiophenols

Basic Compounds

Pyridine
Alkylpyrides
Quinoline
Acridine
Carbazole
Alkylacridines
Indole
Alkylindoles
Alkylquinolines
Alkylcarbazoles

TABLE 9G. SUMMARY OF REACTION SCHEMES AND RATE EQUATIONS USED TO MODEL DOLOMITE AND CALCITE REACTIONS IN OIL SHALE

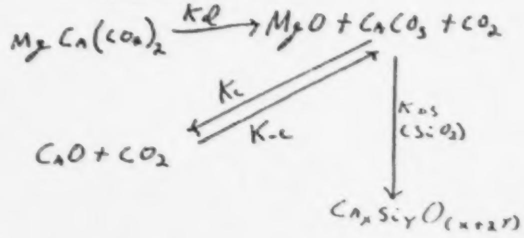
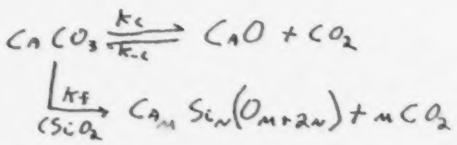
Mineral	Reaction Scheme	Rate Equations	Physical Description of Terms in Rate Equations
Dolomite		$-\frac{dD}{dt} = K_d D$	Decomposition of Dolomite
		$-\frac{dCd}{dt} = -K_d D$	Formation of Calcite from Dolomite
		$+K_c\left(1-\frac{P_{CO_2}}{K_{eq}}\right)(Cd)$	Decomposition of Calcite (Cd) to C_A0
		$+K_{DS}(\Delta CaO)(Cd)$	Reaction of Calcite (Cd) with SiO_2
Calcite		$-\frac{d(Cf)}{dt} = K_c\left(1-\frac{P_{CO_2}}{K_{eq}}\right)Cf$	Decomposition of Calcite (Cf) to C_A0
		$+K_f(\Delta CaO)Cf$	Reaction of Calcite (Cf) with SiO_2
Calcium Oxide	(see above)	$\frac{d(CaO)}{dt} = K_c\left(1-\frac{P_{CO_2}}{K_{eq}}\right)$ $\times[(Cf)+(Cd)]$	CaO Formation from "free" Calcite (cf) and Calcite from Dolomite (Cd)
Calcium Silicates	(see above)	$d(CS) = \Delta CaO\left(\frac{K_f}{m}(Cf)\right)$	Silicate Formation from "Free" Calcite
		$+\Delta CaO\left(\frac{K_{DS}}{x}(Cd)\right)$	Silicate Formation from Calcite Originating from Dolomite

TABLE 97. MATERIAL EXTRACTED FROM SPENT SHALE AFTER 450 HOURS OF LEACHING WITH ROCK SPRINGS GROUNDWATER

Constituent	Original Groundwater MG/L	Leachate Composition High Temp. Inert Gas MG/L	Leachate Composition Low Temp. Inert Gas MG/L
B	8.5	41.2	--
Ca	6.25	6.25	0.21
Cu	Trace	0.26	0.15
CO_3	3300	1053	3050
F	26.5	26.5	--
Fe	0.77	0.38	0.70
K	38.5	75.8	45.5
Li	0.19	4.17	0.28
Mg	11.75	1.8	9.0
Na	5065	4538	4450
Zn	0.19	0.20	0.19
pH	9.3	12.6	9.55
Sum of Constituents	8458	5748	7556

TABLE 98. EFFECTS OF RETORTING AND LEACHING - WATER TEMPERATURES ON VARIOUS CHARACTERISTICS AND CONSTITUENTS OF UTAH SPENT SHALE LEACHATES

Retort Temp. °C	Leaching Temp. °C	Material Leached g	pH	Conductivity µMho/CM	Boron Micrograms Per ML	Fluoride Micrograms Per ML	Selenium Micrograms Per ML	Arsenic Micrograms Per ML
(Leached in Douglas Creek Water - Air Only)								
430	35	86	8.55	4300	1.75	26	--	--
430	90	86	8.21	4050	1.70	26.2	--	--
780	35	67	12.00	23000	1.75	38.7	<0.1	1
780	90	67	12.30	41400	2.88	41	--	1
1000	35	68	11.48	10980	6.10	33.7	<0.1	1
1000	90	68	11.44	12580	8.3	33.7	<0.1	1
(Leached in Bird's Nest Creek Water - Air Only)								
430	35	86	8.67	8480	1.75	23.8	--	--
430	90	86	8.22	7580	1.8	24.5	--	--
780	35	67	12.15	33000	2.15	37.8	--	--
1000	35	68	11.28	13600	9.2	25.5	<0.1	1
1000	90	68	11.03	14840	6.7	23.1	<0.1	1
(Leached in Douglas Creek Water - Air + 15% CO_2)								
430 (Run 1)	35	86	8.3	5610	2.3	23.6	<0.1	--
430 (Run 1)	90	86	7.73	6210	1.75	24.2	--	0
430 (Run 2)	35	85	9.39	5250	1.95	25.6	<0.1	--
430 (Run 2)	90	85	8.29	5700	1.9	26.2	<0.1	--
780	35	67	11.84	12580	3.5	37.5	<0.1	1
1000	35	65	11.47	8770	2.1	35.7	--	--
1000	90	65	11.39	7310	2.15	35	<0.1	1

TABLE 98 (Continued)

Retort Temp. °C	Leaching Temp. °C	Material Leached g	pH	Conductivity µMho/CM	Boron Micrograms Per ML	Fluoride Micrograms Per ML	Selenium Micrograms Per ML	Arsenic Micrograms Per ML
(Leached in Bird's Nest Creek Water - Air + 15% CO_2)								
430 (Run 1)	35	86	8.63	8930	1.6	24.3	--	0
430 (Run 1)	90	86	7.36	11000	1.8	25.6	--	--
430 (Run 2)	35	85	9.52	8700	1.94	23	--	--
430 (Run 2)	90	85	8.28	9270	1.35	22.4	--	--
780	35	67	12.35	26800	2.55	35.7	--	--
780	90	67	12.49	43800	3.1	36.5	<0.1	--
1000	35	65	11.23	12770	2.2	25	<0.1	--
1000	90	65	10.61	9580	2.1	24.5	<0.1	0

TABLE 99. LEACHATE COMPOSITION OF SIMULATED IN-SITU SPENT SHALE

	Experimenter											
	Amy (1978)			Jackson et al. (1975)	Hall et al. (1978)	Parker (1977)				Kun et al. (1977)		
	LLL 125-kg retort			LETC 10-ton High temp comb	LETC 10-ton High temp Steam-comb	Laboratory-scale retort				Laboratory-scale retort[d]	Field Retort 1E	
	Low temp. inert	High temp. combustion	High temp. comb. recycle			Low temp. inert	High temp. inert	Low temp. comb.	High temp. comb.	High temp steam	High temp steam	
Experiment type[a]	B,C	B,C	B,C	B	C	B	B	B	B	B	B	
Particle size range, in.	0.06-0.3	0.06-0.3	0.06-0.3	1-12	0.1-0.5	2x1.5 cores	2x1.5 cores	2x1.5 cores	2x1.5 cores	--	--	
Contact time, batch	30 days	30 days	30 days	5 min	--	15 hr	15 hr	15 hr	15 hr	--	Soxhlet extraction	
Pore values for continuous-flow columns	31	31	31	--	17	--	--	--	--	--	--	
Constituent	Constituent concentration, mg/100 g											Data summary, simulated in situ retorts
Al	--	--	--	--	--	0.38-1.4	1.6-2.3	0.095-1.4	--			0.095-2.3
B	--	--	--	0.025-0.14	--	--	--	--	--	0.01-0.33	0.001-0.010	0.001-0.14
Ca	--	--	--	3.67-67	--	6.1-14	44-49	97-160	68-210	1.4-2.5	0.03-0.21	0.03-210
Cl	--	--	--	5.5	--	--	--	--	--	--	--	5.5
CO3	--	--	--	30-215	--	--	--	--	--	--	--	30-215
Cr	--	--	--	--	--	--	0.002-0.304	0.020-0.11	Tr-1.3	--	--	0.002-1.3
F	--	--	--	1.2-4.2	--	--	--	--	--	--	--	1.2-4.2
Fe	--	--	--	--	--	0.0001-0.0005	0.0005-0.0006	0.003-0.042	0.001-0.024	--	--	0.0001-0.042
HCO3	--	--	--	22-40	--	--	--	--	--	--	--	22-40
K	--	--	--	[illegible]	--	0.26-0.34	1.2-2.4	2.1-3.4	5.2-13	0.1-1.25	0.07-1.2	0.07-13
Li	--	--	--	--	--	0.020-0.10	0.31-0.31	0.092-0.14	0.091-0.32			0.020-0.32
Mg	--	--	--	0.23-4.3	--	0.022-0.38	0.031-0.140	0.012-3.0	[illegible]		0.006-0.02	0.002-3.0
Mn	--	--	--	--	--	Tr	Tr	Tr	Tr			Tr[b]
Na	--	--	--	12-235	--	12-21	9.3-41	22-35	11-77	0.2-0.55	0.05-0.21	0.05-235
NO3	--	--	--	0.2-2.5	--	--	--	--	--	--	--	0.2-2.6
OH	--	--	--	22-41	--	--	--	--	--	--	--	22-40
Pb	--	--	--	--	--	--	0.011-0.017	--	--	--	--	0.011-0.017
Si	--	--	--	25-43	--	--	--	--	--			25-43
SO4	--	--	--	50-133		--	--	--	--	1.8-2.3	0.28-0.60	0.28-133
Sr	--	--	--	--		0.004-0.01	0.60-2.3	1.4-2.4	1.5-4.7	--	--	0.004-4.7
Zn	--	--	--	--		0.001-0.11	0.006-0.125	0.011-0.070	0.003-[illegible]	--	--	0.001-0.125
TDS	3-1130[c]	250-2700[c]	520-2300[c]	251-762		30-134	613-1120	135-553	615-[illegible]	--	--	[illegible]-330
TOC	1.5-6.7[c]	1.3-4.4	2.9-11.7[c]	18-35	10.0-12.6	--	--	--	--	--	--	1.0-30
Organic N	0.07-0.14	0.07-0.09	0.06-0.11	--	--	--	--	--	--	--	--	0.06-0.14
Phenols	0.03-0.04	0.02-0.03	0.015-0.027	--	--	--	--	--	--	--	--	0.02-0.04
pH	[illegible]-10	11-12	11-12	10.4-11.2	--	8.23-10.6	11.6-12.0	7.76-12.0	12.0-12.2	--	--	7.76-12.7

[a] B = batch; C = continuous flow.

[b] Tr indicates a trace detected.

[c] Upper limit derived with 30-hr continuous flow columns, see Tables 6-1 and 6-2.

[d] Water to shale ratio varied from 2 to 25 l/kg.

TABLE 100. RETORT 3E CORE SOXHLET RESULTS LEACHABLE MINERAL CONCENTRATION, Mg/g SHALE

Sample Depth, ft.	Ca	Mg	Na	K	SO_4	B	As*
442-445	1.5	0.214	0.63	1.16	5.7	0.046	<0.15
468-469	0.7	0.092	1.48	0.94	5.5	0.100	0.38
468-469	0.5	0.100	1.30	0.69	3.6	0.064	0.53
469-470.5	0.77	0.110	1.05	0.94	3.1	0.029	<0.15
470-475	0.97	0.149	1.02	0.97	3.1	0.034	0.49
475-477	1.14	NA	1.24	12.2	6.0	0.030	NA
475-477	0.30	NA	1.26	1.56	4.9	0.040	0.48
475-477	0.77	0.249	1.13	1.22	5.4	NA	NA
475.5-477.5	0.53	0.063	1.08	1.24	3.1	0.027	0.61
477-480	2.08	0.135	2.06	2.85	6.6	0.063	1.61
480.5-481.5	0.61	0.066	1.35	1.35	5.7	0.032	0.84
481.5-483.5	0.97	0.080	0.54	0.82	4.9	0.011	<0.15
481.5-483.5	0.79	0.079	1.07	1.40	4.0	0.024	0.16
483-485	0.92	0.073	0.48	0.70	2.9	0.035	<0.15
483.5-485.5	1.43	0.143	0.95	1.19	4.9	0.008	1.43
485.5-500.5	0.99	0.091	1.03	1.01	3.9	0.011	0.38
500-506	1.17	0.111	1.14	1.34	2.8	0.021	0.65
Mean	0.95	0.117	1.11	1.21	4.3	0.036	
Std. Dev.	0.43	0.054	0.37	0.49	1.1	0.024	

*Unit for arsenic = microgram per gram.

NA = no analysis.

TABLE 101. LEACHABILITY FOR VARIOUS SHALES DETERMINED BY SOXHLET EXTRACTION

	Leachable Mineral Concentration Mg/g of Shale				
	Ca	SO_4	Na	K	B
Retort 3E Samples	0.95	4.3	1.11	1.21	0.036
Pilot Plant Samples	4-25	8-28	2-5.5	1-2.5	0.11-0.32
Raw Shale	0.280	5.4	1.11	0.038	0.046

TABLE 102. EXPERIMENTAL VARIABLES EXAMINED IN LEACHING EXPERIMENTS

Variable	Kinetic Batch Experiments	Equilibrium Batch Experiments	Column Batch Experiments
Particle Size Range	X		
Retorting Conditions	X	X	X
Leaching Time Period	X		X
Water Temperature	X	X	
Water Quality	X	X	
Shale to Water Ratio		X	
Column Length			X
Rate of Flow			X

TABLE 103. RETORTING CHARACTERISTICS OF SPENT SHALE SAMPLES

Retorting Characteristic	Type 1 Shale	Type 2 Shale	Type 3 Shale	Type 4 Shale
Type of Retorting Run	Combustion	Inert Gas	Combustion	Inert Gas
Input Gas	Air + N_2 (7.6% O_2)	N_2	Air + Recycle Gas (10.5% O_2)	N_2
Maximum Retorting Temperature, °C	750	510	935	460-530
Retorting Rate, M/Day	0.69	1.40	1.34	≈2
Oil Yield (% of Fischer Assay)	78	99	96	NR

TABLE 104. PHYSICAL AND CHEMICAL CHARACTERISTICS OF SPENT SHALE SAMPLES

	Spent Shale Sample			
Characteristic	Type 1	Type 2	Type 3	Type 4
Physical Characteristics				
Min. Particle Size, CM	0.14	0.14	0.14	0.14
Max. Particle Size, CM	0.64	0.64	0.64	0.64
Bulk Density, g/CC	0.86	1.08	0.80	0.95
Solid Density, g/CC	2.0	2.2	2.0	2.1
Porosity, %	57	51	60	54
Permeability, Gal/Day/Ft^2	560	510	490	710
Chemical Characteristics				
Organic Carbon, % by Wt.	0.2	1.8	2.1	3.9

TABLE 105. TOTAL ORGANIC CARBON LEACHED FROM VARIOUS TYPES OF SPENT SHALE DURING KINETIC BATCH EXPERIMENTS

	Total Organic (TOC) Leached, MG/100 G of Spent Shale			
Experiment Type	**Type 1**	**Type 2**	**Type 3**	**Type 4**
30-Day Distilled Water Batch, 20°C	1.1	1.9	3.5	1.7
30-Day Distilled Water Batch, 80°C	1.3	3.1	2.9	3.1
30-Day Groundwater Batch, 20°C	1.0	2.3	3.8	2.0
30-Day Groundwater Batch, 80°C	1.0	5.8	3.4	4.7
Initial Solid-Phase Organic Carbon Content of Spent Shale MG/100 G of Spent Shale	200	1800	2100	3900

TABLE 106. ACID, BASE, AND NEUTRAL FRACTIONS OF ORGANIC MATERIAL IN COMPOSITE SAMPLES DERIVED FROM BATCH EXPERIMENT

		Mass of Organic Material, MG/100 g of Spent Shale			
Batch Experiment		**Type 1**	**Type 2**	**Type 3**	**Type 4**
Distilled Water	Acid	0.68	0.37	0.36	0.88
20°C	Base	0.46	0.51	0.29	0.54
	Neutral	0.86	0.88	0.28	1.05
	Total	2.00	1.76	0.93	2.47
Distilled Water	Acid	0.50	0.45	0.33	0.72
80°C	Base	0.61	0.33	0.47	0.36
	Neutral	0.18	0.35	0.52	0.89
	Total	1.29	1.13	1.32	1.97
Groundwater	Acid	0.42	0.92	--	--
20°C	Base	0.37	0.44	--	--
	Neutral	0.66	1.60	--	--
	Total	1.45	2.96	--	--
Groundwater	Acid	0.50	1.10	--	--
80°C	Base	0.33	0.59	--	--
	Neutral	0.36	2.30	--	--
	Total	1.19	3.99	--	--

TABLE 107. ORGANIC NITROGEN IN COMPOSITE SAMPLES DERIVED FROM BATCH EXPERIMENTS

Batch Experiments	Type 1			Type 2			Type 3			Type 4		
	Conc.[A]	Mass[B]	C/N[C]	Conc.	Mass	C/N	Conc.	Mass	C/N	Conc.	Mass	C/N
Distilled Water, 20°C	0.7	0.07	16	0.7	0.07	27	0.9	0.09	39	1.0	0.1	17
Distilled Water, 80°C	0.4	0.04	33	0.7	0.07	44	1.3	0.13	22	1.4	0.14	22
Groundwater, 20°C	0.9	0.09	11	0.9	0.09	26	0.7	0.07	54	0.9	0.09	22
Groundwater, 80°C	0.7	0.07	14	0.9	0.09	64	0.6	0.06	57	1.2	0.12	39

A = Concentration, MG/L.

B = Mass leached per unit mass, MG/100 G.

C = Ratio of organic carbon to organic nitrogen.

TABLE 108. PHENOLS IN COMPOSITE SAMPLES FROM BATCH EXPERIMENTS

Phenols in Composite Samples	Batch Experiment Distilled Water, 20°C	 Distilled Water, 80°C
Type 1		
Conc.[A]	0.25	0.23
Mass[B]	0.025	0.023
Type 2		
Conc.	0.43	0.30
Mass	0.043	0.030
Type 3		
Conc.	0.22	0.15
Mass	0.022	0.015
Type 4		
Conc.	0.41	0.35
Mass	0.041	0.035

TABLE 109. EQUILIBRIUM BATCH EXPERIMENTS: ORGANIC CARBON CONCENTRATION AND MASS OF ORGANIC CARBON LEACHED PER UNIT MASS OF SPENT SHALE

	Shale-To-Water Ratio							
	Type 1				Type 2			
	50G/30ML	50G/50ML	50G/100ML	50G/200ML	50G/30ML	50G/50ML	50G/100ML	50G/200ML
	Concentration of Organic Carbon MG/L							
Distilled Water, 20°C	18	11	5.0	3.9	25	19	11	5.4
Distilled Water, 80°C	16	13	6.9	4.9	36	31	24	15
Ground-Water, 20°C	19	10	6.9	3.6	25	23	10	6.7
Ground-Water, 80°C	16	10	7.7	4.4	67	58	38	17
	Mass of Organic Carbon Leached Per Unit Mass, MG/100G							
Distilled Water, 20°C	1.1	1.1	1.0	1.6	1.5	1.9	2.2	2.2
Distilled Water, 80°C	1.0	1.3	1.4	2.0	2.2	3.1	4.8	6.0
Ground-Water, 20°C	1.1	1.0	1.4	1.4	1.5	2.3	2.0	2.7
Ground-Water, 80°C	1.0	1.0	1.5	1.8	4.0	5.8	7.6	6.8

TABLE 110. TOTAL ORGANIC CARBON LEACHED FROM VARIOUS TYPES OF SPENT SHALE: COMPARISON OF CONTINUOUS FLOW COLUMN EXPERIMENTS AND BATCH EXPERIMENTS

		Total Organic Carbon Leached, Mg/100G of Spent Shale			
Experiment Type	Water Type	Type 1	Type 2	Type 3	Type 4
12 in. Cont. Flow Column	Distilled	3.8	4.1	9.7	6.1
6 in. Cont. Flow Column	Distilled	4.4	5.0	11.8	6.9
Batch, 20°C	Distilled	1.1	1.9	3.5	1.7

TABLE 111. WEIGHT (W) AND BULK DENSITY (D) OF SPENT SHALE SAMPLES COMPACTED INTO COLUMNS

	Column Length, In.	
	12	6
Type 1		
W, g	206	102
D, G/CC	1.40	1.39
Type 2		
W, g	210	106
D, g/CC	1.43	1.44
Type 3		
W, g	168	84
D, g/CC	1.14	1.14
Type 4		
W, g	186	93
D, g/CC	1.26	1.26

TABLE 112. MASSES OF POTENTIALLY LEACHABLE ORGANIC CARBON

	Potentially Leachable Organic Carbon, MG/L TOC/100 G Spent Shale		
Type of Leach Water	Water Temp. °C	Type 1 Shale A	Type 2 Sh
Distilled Water	20	1.6-4.4	2.2-5.
Distilled Water	80	2.0	6.0
Groundwater	20	1.4	2.7
Groundwater	80	1.8	6.8

A) Type 1 is a combustion retorted spent shale

B) Type 2 is an inert gas retorted spent shale

TABLE 113. ESTIMATED SATURATION CONCENTRATIONS OF ORGANIC CARGON

	Concentration of Organic Carbon, MG/L TOC		
Type of Leach Water	Water Temp. °C	Type 1 Shale	Type 2 Shale
Distilled Water	20	18-440	25-790
Distilled Water	80	16-90	36-63
Groundwater	20	19-1270	25-530
Groundwater	80	16-152	67-140

TABLE 114. ESTIMATED MINIMUM MASS OF ORGANIC CARBON THAT CAN POTENTIALLY BE LEACHED FROM A TYPICAL IN SITU RETORT

	Organic Carbon, KG TOC		
Type of Leach Water	Water Temp. °C	Type 1 Shale	Type 2 Shale
Distilled Water	20	2400-6,600	3,300-7,500
Distilled Water	80	3,000	9,000
Groundwater	20	2,100	4,100
Groundwater	80	2,700	10,000

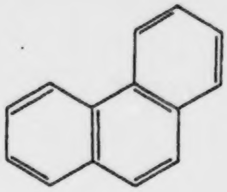
TABLE 115. PORE VOLUMES OF WATER REQUIRED TO LEACH ESTIMATED MINIMUM MASS OF POTENTIALLY LEACHABLE ORGANIC CARBON FROM A TYPICAL RETORT

	Pore Volumes of Water[A]		
Type of Leach Water	Water Temp. °C	Type 1 Shale	Type 2 Shale
Distilled Water	20	1.7-4.7	1.7-3.9
Distilled Water	80	2.5	3.3
Groundwater	20	1.5	2.1
Groundwater	80	2.3	2.0

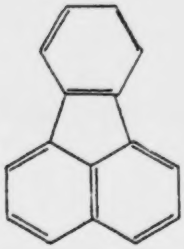
[A] One pore volume is equal to 7.5×10^7 liters

TABLE 116. COMPOUNDS IDENTIFIED IN BENZENE EXTRACT OF CARBONALCEOUS SHALE COKE FROM GREEN RIVER OIL SHALE

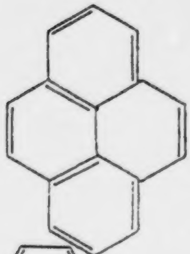
PHENANTHRENE



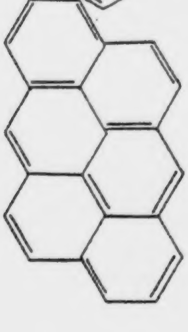
FLUORANTHENE



PYRENE



ANTHANTHRENE (DIBENZO[cdjk]PYRENE)



BENZ[A]ANTHRACENE

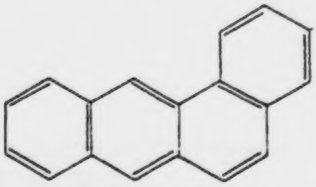


TABLE 116. (Continued)

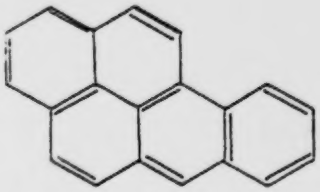
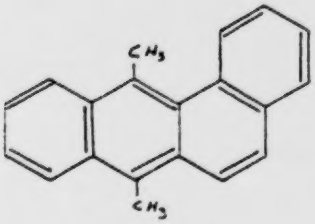
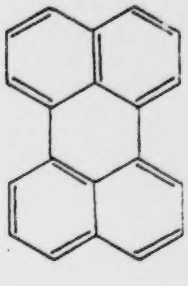
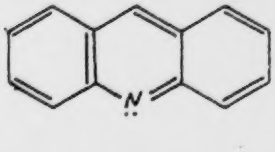
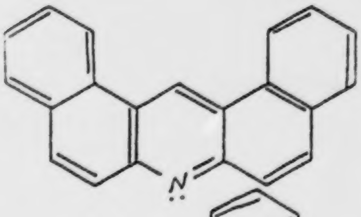
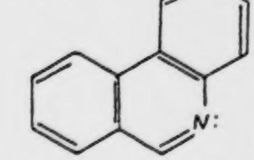
BENZO[A]PYRENE	
7,12-DIMETHYL[A]ANTHRACENE	
PERYLENE	
ACRIDINE	
DIBENZ[A;J]ACRIDINE (1,2,-7,8-DIBENZACRIDINE)	
PHENANTHRIDINE	

TABLE 116 (Continued)

CARBAZOLE

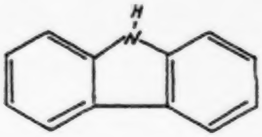


TABLE 117. IDENTIFIED BENZENE LEACHABLES

Molecular Weight	Compound
134	Benzene, Di- or Tri-Alkyl substituted
154	1 - Undecene
156	Undecane
132	Benzene, Di-Alkyl-Alkenyl- substituted
148	Benzene, Alkyl substituted
128	Naphthalene or Azulene
168	1 - Dodecene
170	Dodecane
184	Undecane, Dimethyl
142	Naphthalene, Methyl
182	1 - Tridecene
184	Tridecane
174	Naphthacene, 1,2,3,4-Tetra Hydro-Tri-Alkyl substituted
154	1,1' B, Phenyl or acenaphthycene, 1, 2-Dihydro
156	Naphthacene, Mono - or Di-Alkyl substituted
196	1 - Tetradecene
198	Tetradecane
170	Naphthacene, Trimethyl substituted
210	1 - Pentadecene
212	Pentadecane
184	Naphthacene, Alkyl substituted
224	1 - Hexadecene
226	Hexadecane
238	1 - Heptadecene
240	Heptadecane
268	Alkane, substituted
198	Dibenzothiophene, Methyl substituted
252	1 - Octadecene
254	Octadecane
192	Phenanthrene or Anthracene, Methyl substituted

TABLE 117. (Continued)

Molecular Weight	Compound
266	1 - Nonadecene
268	Nonadecane
206	Phenanthrene, Dimethyl substituted
280	1 - Eicosene
282	Eicosane
294	1 - Heneicosene
296	Heneicosane
216	Pyrene, Methyl substituted or II H-Benzo [A] Fluorene
216	Pyrene, Methyl substituted
308	1 - Docosene
310	Docosane
322	1 - Tricosene
324	Tricosane
336	1 - Tetracosene
338	Tetracosane
350	1 - Pentacosene
352	Pentacosane
364	1 - Hexacosene
366	Hexacosane
378	1 - Heptacosene
380	Heptacosane
392	1 - Octacosene
394	Octacosane
408	Nonacosane

TABLE 118. SUMMARY OF POLYNUCLEAR HYDROCARBONS FROM THIN LAYER CHROMATOGRAPHY EXPERIMENTS

Anthracene
Phenanthrene
Pyrene
Fluoranthene
Benzo (A) Anthracene
Chrysene
Triphenylene
Benzo (C) Phenanthrene

TABLE 119. SULFUR HETEROCYCLES IN SHALE OIL

Molecular Weight	Compound
136	2,3 - Dihydrobenzo[B] thiophene
150	C_1 - Dihydobenzo [B] thiophene
148	C_1 - Benzo [B] thiophene
150	C_1 - Dihydrobenzo [B] thiophene
164	C_2 - Dihydrobenzo [B] thiophene
162	5 - Ethylbenzo [B] thiophene
162	C_2 - Benzo [B] thiophene
178	C_3 - Dihydrobenzo [B] thiophene
176	C_3 - Benzo [B] thiophene
192	C_4 - Dihydrobenzo [B] thiophene
190	C_4 - Benzo [B] thiophene
206	C_5 - Dihydrobenzo [B] thiophene
184	Dibenzothiophene (and 1 or Naphtho [1, 2-B] thiophene)
198	C_1 - Dibenzothiophene
212	C_2 - Dibenzothiophene
208	Phenanthro [4, 5 -BCD] thiophene
224	C_3 - Dibenzothiophene
222	C_1 - Phenanthro [4, 5-BCD] thiophene
234	Benzo [2, 1-D] thiophene (and/or benzo [B] naphto [2,3-D] thiophene)
234	Phenanthro [1, 2-B] thiophene (and/or phenanthro [4, 3-B] thiophene)
248	Isomers of C_1 - Benzo [B] naptho [2, 1-D] thiophene
262	Isomers of C_2 - benzo [B] naptho [2,1-D] thiophene
258	Triphenyleno [4,5-BCD] thiophene

TABLE 120. ESTIMATED COMPOSITION OF LEACHATE EXITING AN IN SITU RETORT LOCATED ON LEASE TRACTS C-a AND C-b

	Predevelopment Groundwater Quality, MG/L				Leachate Composition MG/L	
	C-a		C-b			
Constituent	Upper AQ	Lower AQ	Upper AQ	Lower AQ	C-a	C-b
Al	0.14	0.24	0.3	0.3	0.49 → 31	0.89 - 53
B	0.33	0.84	1.4	36	0.33 → 1.9	36 → 39
Ca	35	8.8	32	14	35 → 2350	14 → 3950
Cl	12	22	26	1200	32 → 73	1234→ 1300
CO_3	0.88	69	21	220	110 → 2400	408→ 4250
Cr	<0.01	<0.01	0.002→0.3	<0.009	<0.02 → <20	0.01 → 34
F	0.41	15	10	21	4.8 → 47	29 → 100
Fe	5.0	0.78	0.5	0.8	5.0 → 5,5	0.8 → 1.6
HCO_3	482	842	790	4000	560 → 920	4140 → 4750
K	2.2	2.6	2.2	21	2.5 → 200	21 → 360
Li	0.13	0.13	<3.1	10	0.2 → 4.8	10 → 18
Mg	52	20	42	11	52→ 140	11 → 160
Na	212	397	330	2500	212 → 2800	2500 → 6900
NO_3	0.21	0.1	0.41	0.46	0.94→ 30	1.7 - 49
Pb	0.17	0.21	0.01	0.03	0.22→ 0.36	0.12→ 0.35
Si	26	10	17	13	120→ 990	170 → 1660
SO_4	325	112	220	63	326→ 1800	65 → 2500
Zn	0.26	0.24	0.2	0.2	0.26→ 0.54	0.2 → 0.7
TDS	905	1075	1100	6190	905→31,700	6190→58,700
TOC	8.5	11	3	10	12→430	16 → 720
PHENOLS	0.003	0.002	-	-	0.04→ 0.44	0.66→ 0.8

TABLE 121. RETORT OPERATING CONDITIONS FOR LETC'S CONTROLLED STATE RETORT USING GREEN RIVER OIL SHALE

Run	Run Type[A]	Shale Grade (Liters/Tonne)	Shale Size Range (Mn)	Oil Yield 0/0 Fisher Assay	Isothermal Advance Rate (M/Day)	Max. Temp. (^{o}C)	Sweep Gas 0/0	Gas Flow Rate Min(M^3/M^2)
CS-31	I	125	10-19	43	1.83	540	N_2	0.12
CS-32	I	125	3-10	33	1.83	540	N_2	0.12
CS-35	C	140	3-13	101	1.83	540	N_2	0.12
CS-37	I	125	3-13	30	0.04	540	N_2	0.01
CS-56	C	123	3-13	71	0.04	540	N_2	0.002
CS-57	C	123	3-13	98	1.84	540	N_2	0.12
CS-59	C	88	3-13	111	7.32	565	N_2	1.21
CS-60	I	123	3-13	46	1.83	540	N_2	0.12
CS-61	C	88	3-13	92	1.83	540	N_2	0.12
CS-64	C	248	3-13	94	1.83	540	N_2	0.12
CS-66	C	128	3.13	91	1.83	540	75/N_2 25/Steam	0.15
CS-67	C	231	3-13	100	1.83	540	75/N_2 25/steam	0.15
CS-68	C	119	3-13	97	1.83	540	N_2	0.12
CS-69	C	118	3-13	98	1.83	760	64.5 N_2 10.5 O_2 25 steam	0.15
CS-70	C	134	3-13	96	1.83	540	75 N_2 25 steam	0.15
CS-72	C	89	3-13	97	1.83	540	75 N_2 25 steam	0.15
CS-74	C	82	3-13	102	1.83	760	64.5 N_2 10.5 O_2 25 steam	0.15

[A] C = Completed Run
I = Interrupted Run

TABLE 122. RETORT OPERATING CONDITIONS FOR LLL'S SIMULATED IN SITU RETORTS, COLORADO SHALE

Run	Shale Grade (Liters/Tonne)	Void Fraction (0/0)	Shale Size (M/M)	Oil Yield 0/0 Fisher Assay	Isothermal Advance Rate (M/Day)	Avg. Max Centerline Temp (^{o}C)	Sweep Gas	Volume 0/0 O_2	Gas Flow Rate (M^3/M^2 Min)
S-7	100	46	13-25	78	0.7	741	Air+N_2	7.6	0.45
S-9	100	47	13-25	98	1.4	494	N_2	0	1.06
S-10	100	47	13-25	95	1.3	868	Air + Recycle	11.8	0.64
S-11	100	47	13-25	92	2.6	1003	Air	21.0	0.61
S-12	100	38	0.01-76	93	2.1	942	Air+N_2	8.92	1.14
S-13	100	49	13-25	96	2.2	887	Air + Steam	10.6	0.72
S-14	100	34	0.01-76	88	1.6	1010	Air + Steam	10.6	0.7
S-15	84	37	0.01-25	86	1.5	1025	Air + Steam	10.6	0.7
L-1	108	25	0-76 + Blocks	72	1.7	995	Air+N_2	8.7	1.1

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TABLE 123. AVERAGE ELEMENTAL ABUNDANCES OF GREEN RIVER OIL SHALES

Element	Abundance (PPM) or 0/0
Al (0/0)	3.53
As	36
Ba	440
C (0/0)	18.8
Ca(0/0)	9.8
Cd	0.84
Ce	39.1
Co	9.73
Cr	34
Cs	4.33
Cu	37
Dy	2.10
Eu	0.57
Fe(0/0)	1.92
Ga	7.7
H(0/0)	2.0
Hf	1.54
Hg	0.12
K(0/0)	1.39
La	20
Lu	0.15
Mg(0/0)	3.47
Mn	289
Mo	26
N(0/0)	0.63
Na(0/0)	1.77
Nd	17
Ni	20
Pb	23
Rb	62
S(0/0)	0.87
Sb	2.05

TABLE 123. (Continued)

Elements	Abundance (PPM) or 0/0
Sc	5.53
Se	1.9
Si(0/0)	13.6
Sm	2.71
Sr	677
Ta	0.42
Tb	0.36
Th	5.82
Ti(0/0)	0.13
U	4.48
V	109
W	1.6
Y	8.8
Yb	1.17
Zn	60

TABLE 124. AVERAGE ELEMENTAL ABUNDANCES IN GREEN RIVER SPENT SHALE

Element	Abundance (PPM) or 0/0
Al(0/0)	4.51
As	53
Ba	609
((Org.)(0/0)	3.6
((Inorg)(0/0)	3.2
Ca	12.0
Cd	0.81
Ce	53
Cl	4
Co	12.3
Cr	46
Cs	5.97
Cu	51
Dy	2.85
Eu	0.78
F ~~D~~e(0/0)	2.69
Ga	11
H(0/0)	0.19
Hf	2.24
Hg	0.03
K(0/0)	2.00
La	26
Lu	0.21
Mg(0/0)	4.61
Mn	396
Mo	30
N(0/0)	0.28
Na(0/0)	2.34
Nd	21
Ni	31
Pb	30
Rb	89

TABLE 124. (Continued)

Element	Abundances (PPM) or 0/0
S(0/0)	0.59
Sb	2.75
Si	7.45
Se	2.8
Si(0/0)	18.8
Sm	3.69
Sr	899
Ta	0.61
Tb	0.45
Th	8.36
Ti(0/0)	0.19
U	6.17
V	136
W	2.0
Y	17
Yb	1.65
Zn	87

TABLE 125. MOBILITY OF SOME MAJOR, MINOR, AND TRACE ELEMENTS IN GREEN RIVER OIL SHALES

Group	Element	Mobility 0/0
1	H	94 ± 3
	Hg	70 ± 20
	C	64 ± 7
	N	49 ± 7
	S	44 ± 8
	Cd	29 ± 7
2	Se	5.1 ± 1.0
	Ni	4.7 ± 1.3
	As	3.8 ± 1.3
	Co	3.8 ± 0.8
3	Cr	0.38 ± 0.78
	Sb	0.28 ± 0.15
	Zn	0.27 ± 0.28
	Cu	0.27 ± 0.33
	Na	0.19 ± 0.10
	Mo	0.18 ± 0.11
	V	0.11 ± 0.03
	Ga	0.10 ± 0.07
	Fe	0.084 ± 0.081
	Mn	0.056 ± 0.071
	U	0.040 ± 0.023
	Ba	0.035 ± 0.022
	Dr	0.034 ± 0.017
	La	0.024 ± 0.019
	K	0.023 ± 0.022
	Mg	0.021 ± 0.019
	Sn	0.020 ± 0.019
	Cs	0.019 ± 0.019
	Eu	0.018 ± 0.013
	Hf	0.014 ± 0.028
	Rb	0.014 ± 0.009

TABLE 125. (Continued)

Group	Element	Mobility 0/0
3 (Cont.)	Ce	0.013 ± 0.007
	Sr	0.012 ± 0.016
	Al	0.0062 ± 0.0035
	Ca	0.003 ± 0.0025
	Sc	0.0057 ± 0.0025
	Ti	0.0090 ± 0.015
	Yb	0.0033 ± 0.0010
	Th	0.0076 ± 0.0081

TABLE 126. MASS DISTRIBUTION PATTERNS OF GROUP 2 ELEMENTS, 0/0

	LLL	LETC
Nickel		
Spent Shale	98.0 ± 1.4	95.4 ± 1.0
Oil	1.3 ± 0.4	4.4 ± 1.0
Water	0.3 ± 0.5	0.2 ± 0.1
Gas	0.0	0.0
Cobalt		
Spent Shale	99.2 ± 0.4	96.2 ± 0.9
Oil	0.8 ± 0.4	3.7 ± 0.8
Water	0.0	0.1 ± 0.1
Gas	0.0	0.0
Arsenic		
Spent Shale	96.9 ± 1.2	96.3 ± 1.2
Oil	3.0 ± 1.2	3.4 ± 1.2
Water	0.1 ± 0.1	0.3 ± 0.1
Gas	0.0	0.0
Selenium		
Spent Shale	71.9 ± 4.6	94.9 ± 1.0
Oil	9.5 ± 4.2	4.6 ± 0.8
Water	2.8 ± 2.0	0.5 ± 0.5
Gas	15.9 ± 6.4 A,B	0.0

A) Values for runs S-11 → s-15 + L-1

B) Computed by difference

TABLE 127. CONCENTRATION OF MERCURY IN RAW OIL SHALES, SPENT OIL SHALES, SHALE OILS, AND RETORT WATERS FROM LLL AND LETC SIMULATED IN SITU RETORTS.

Run	Raw Oil Shale PPB	Spent Oil Shale, PPB			Shale Oil PPB	Retort Water Microgram/Liter	
		Top	Middle	Bottom		Unfiltered	Particulate
			LETC Controlled State Retort				
CS-60	163 ± 20	151 ± 56	151 ± 56	151 ± 56	<52	29 ± 6	29 ± 8
CS-61	81 ± 9	45 ± 3	45 ± 11	106 ± 18	56 ± 5	-	49 ± 8
CS-62	73 ± 12	58 ± 8	30 ± 1	19 ± 3	<79	49 ± 12	51 ± 9
CS-63	138 ± 10	63 ± 10	69 ± 37	261 ± 78	<61	80 ± 5	55 ± 3
CS-64	273 ± 81	46 ± 21	6330 ± 1310	232 ± 30	42 ± 5	196 ± 5	15 ± 2
CS-65	101 ± 15	11 ± 4	25 ± 4	288 ± 83	59 ± 1	320 ± 25	67 ± 4
CS-66	93 ± 13	14 ± 1	15 ± 3	28 ± 5	<82	160 ± 14	33 ± 3
CS-67	308 ± 81	43 ± 4	13 ± 2	385 ± 48	59 ± 4	95 ± 9	9.92 ± 1.6
CS-68	80 ± 14	24 ± 5	11 ± 2	238 ± 23	39 ± 4	150 ± 14	21 ± 2
CS-69	86 ± 20	<2	17 ± 9	3.0 ± 0.9	54 ± 11	103 ± 13	79 ± 4
CS-70	62 ± 5	1.5 ± 0.3	9.5 ± 2.1	34 ± 5	29 ± 10	98 ± 7	73 ± 5
CS-71	70 ± 4	47 ± 8	44 ± 9	58 ± 5	129 ± 45	50 ± 2	1.9 ± 0.3
CS-72	70 ± 12	24 ± 7	23 ± 2	36 ± 9	-	42 ± 2	-
CS-73	129 ± 16	<31	22 ± 3	157 ± 3	<105	250 ± 25	-
CS-74	79 ± 1	<21	<9	17 ± 1	-	23 ± 4	-
			LLL Retorts				
S-9	84 ± 6	-	36 ± 1	-	64 ± 20	79 ± 5	-
S-10	84 ± 6	-	<10	-	149 ± 38	<0.50	-
S-11	84 ± 6	-	1.1 ± 0.4	-	220 ± 42	85 ± 11	-
S-12	84 ± 6	-	3.9 ± 0.7	-	-	17 ± 2	-
S-13	84 ± 6	-	<10	-	156 ± 35	<16	-
S-14	84 ± 6	-	1.0 ± 0.4	-	368 ± 46	44 ± 4	-
S-15	84 ± 6	-	1.0 ± 0.5	-	369 ± 48	<17	-
L-1	84 ± 6	-	1.0 ± 0.2	-	84 ± 30	19 ± 4	-

Elemental abundances in products from run CS-60 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	.90 ± 0.14*	4.58 ± 0.24*	<0.4	-
As	.4 ± 3.69	53.5 ± 5.3	9.52 ± 0.48	6.35 ± 0.45
Ba	67 ± 24	550 ± 26	1.11 ± 0.12	-
C (org)	.8 ± 1.2*	10.1 ± 0.7*	84.8 ± 8.5*	0.43 ± 0.06*
C (inor)	.20 ± 0.22*	4.41 ± 0.31*	-	0.66*
Ca	10 ± 0.25*	10.8 ± 0.3*	-	26 ± 1
Cd	67 ± 0.15	0.96 ± 0.23	-	0.0038 ± 0.0005
Ce	.8 ± 1.5	49.2 ± 2.5	0.061 ± 0.005	<0.020
Cl	-	-	2.6 ± 0.2	1175 ± 11
Co	.90 ± 0.72	11.7 ± 0.6	2.44 ± 0.02	0.385 ± 0.004
Cr	.9 ± 2.1	43.0 ± 2.5	1.04 ± 0.02	1.40 ± 0.02
Cu	.3 ± 1.3	46.8 ± 3.4	0.65 ± 0.52	0.15 ± 0.08
Dy	.21 ± 0.06	2.58 ± 0.11	0.0045 ± 0.0005	-
Eu	.615 ± 0.022	0.748 ± 0.037	0.0011 ± 0.0002	<0.0004
Fe	06 ± 0.09*	2.48 ± 0.08*	77.9 ± 3.8	23.5 ± 0.9
Ga	.9 ± 0.4	10.2 ± 1.4	0.12 ± 0.03	0.05 ± 0.04
Ge	.4 ± 0.1	1.7 ± 1.2	<0.48	<0.06
H	12 ± 0.18	1.14 ± 0.64	12.3 ± 1.2	-
Hf	.72 ± 0.09	2.06 ± 0.12	0.0017 ± 0.0007	-
Hg	.63 ± 0.02	0.205 ± 0.041	<0.052	0.029 ± 0.006
K	.51 ± 0.13*	1.93 ± 0.30*	7.3 ± 2.1	19 ± 3
La	.1 ± 0.6	24.3 ± 1.3	0.040 ± 0.003	0.12 ± 0.01
Lu	.17 ± 0.01	0.20 ± 0.03	-	-
Mg	.49 ± 0.15*	4.11 ± 0.20*	21.9 ± 1.6	<22
Mn	47 ± 3	361 ± 8	0.521 ± 0.04	0.05 ± 0.02
Mo	.9 ± 1.3	32.8 ± 3.0	0.42 ± 0.04	0.23 ± 0.04
N	76 ± 0.07*	0.63 ± 0.06*	1.92 ± 0.19*	1.00 ± 0.23*
Na	33 ± 0.06	2.28 ± 0.11	60.7 ± 0.4	835 ± 5
Nd	17 ± 2	20 ± 3	-	-
Ni	.6 ± 3.4	26.9 ± 3.9	7.84 ± 0.72	5.44 ± 0.19
Pb	.8 ± 2.4	35.4 ± 8.4	<1.6	<0.24
Rb	.2 ± 2.6	83.4 ± 3.7	<0.69	0.28 ± 0.06
S	79 ± 0.06*	0.72 ± 0.08*	1.01 ± 0.10*	0.15*
Sb	27 ± 0.17	2.83 ± 0.28	0.024 ± 0.001	0.264 ± 0.003
Sc	65 ± 0.18	6.83 ± 0.24	0.0040 ± 0.0001	-
Se	.90 ± 0.25	2.8 ± 0.6	0.90 ± 0.02	0.40 ± 0.01
Si	.4 ± 0.5*	17.4 ± 0.6*	<270	-
Sm	85 ± 0.14	3.40 ± 0.16	0.0044 ± 0.0004	-
Sr	22 ± 24	780 ± 19	0.79 ± 0.58	0.44 ± 0.08
Ta	.44 ± 0.01	0.53 ± 0.02	-	-
Tb	.36 ± 0.02	0.41 ± 0.03	-	-
Th	.56 ± 0.25	7.88 ± 0.59	0.0074 ± 0.0009	<0.18
Ti	.12 ± 0.02*	0.16 ± 0.03*	<0.9	<0.60
U	.96 ± 0.23	5.91 ± 0.42	0.045 ± 0.003	0.118 ± 0.002
V	108 ± 14	124 ± 17	0.9 ± 0.1	0.15
W	.7 ± 0.4	1.9 ± 0.4	-	-
Y	.7 ± 1.0	15.0 ± 1.0	<1.0	<0.15
Yb	23 ± 0.04	1.52 ± 0.06	0.0044 ± 0.0011	-
Zn	.1 ± 2.1	78.5 ± 4.7	3.33 ± 0.14	1.09 ± 0.09

* ent

Table 128

Elemental abundances in products from run CS-61 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.59 ± 0.06	4.14 ± 0.20	23.0 ± 0.7	-
As	23.8 ± 1.2	28.4 ± 1.3	19.9 ± 0.9	4.20 ± 0.03
Ba	543 ± 12	635 ± 16	0.8 ± 0.3	-
C (org)	8.98 ± 0.90*	2.66 ± 0.79*	84.1 ± 8.4*	0.37 ± 0.01*
C (inor)	5.50 ± 0.55*	5.38 ± 0.81*	-	0.83 ± 0.01*
Ca	12.0 ± 0.1*	14.1 ± 0.5*	73 ± 18	-
Cd	0.70 ± 0.02	0.57 ± 0.26	-	-
Ce	40.3 ± 0.6	44.5 ± 0.7	0.033 ± 0.007	<0.006
Cl	-	-	4.1 ± 0.3	359 ± 4
Co	8.17 ± 0.17	9.35 ± 0.18	1.86 ± 0.01	0.313 ± 0.002
Cr	31.4 ± 0.6	36.2 ± 0.7	0.28 ± 0.02	0.78 ± 0.01
Cs	3.36 ± 0.12	3.94 ± 0.13	-	0.016 ± 0.001
Cu	31.5 ± 2.6	36.5 ± 1.2	1.8 ± 0.6	<2.3
Dy	2.21 ± 0.08	2.65 ± 0.09	-	-
Eu	0.586 ± 0.009	0.667 ± 0.010	<0.0004	<0.0002
Fe	1.88 ± 0.03*	2.12 ± 0.11*	96.8 ± 4.8	[illegible].66 ± 0.43
Ga	7.8 ± 1.2	9.5 ± 1.2	<0.51	-
Ge	<1.2	<1.8	<0.48	-
H	1.32 ± 0.13*	0.11 ± 0.08*	12.1 ± 1.2*	-
Hf	1.54 ± 0.05	1.96 ± 0.05	-	0.0022 ± 0.0004
Hg	0.081 ± 0.009	0.048 ± 0.011	0.056 ± 0.005	-
K	1.63 ± 0.02*	1.81 ± 0.09*	-	-
La	19.6 ± 0.7	21.9 ± 0.7	0.023 ± 0.003	0.040 ± 0.004
Lu	0.17 ± 0.01	0.21 ± 0.02	-	-
Mg	3.76 ± 0.06*	4.39 ± 0.19*	28.9 ± 2.1	<8
Mn	332 ± 7	384 ± 21	0.626 ± 0.006	0.128 ± 0.009
Mo	18.4 ± 1.5	20.5 ± 1.9	0.16 ± 0.06	0.34 ± 0.02
N	0.54 ± 0.05*	0.29 ± 0.02*	1.36 ± 0.16*	1.83 ± 0.01*
Na	1.64 ± 0.04*	2.05 ± 0.17*	141.6 ± 0.8	635 ± 4
Nd	16 ± 1	18 ± 2	-	-
Ni	14.4 ± 3.6	19.9 ± 2.7	9.58 ± 0.78	1.77 ± 0.11
Pb	18.9 ± 1.3	24.2 ± 2.0	<1.6	-
Rb	59.5 ± 2.4	69.0 ± 2.1	<0.69	0.10 ± 0.02
S	0.78 ± 0.08*	0.41 ± 0.17*	0.57 ± 0.06*	0.12 ± 0.01*
Sb	1.36 ± 0.11	1.54 ± 0.12	0.013 ± 0.002	0.105 ± 0.001
Sc	5.46 ± 0.15	6.19 ± 0.17	0.0034 ± 0.0002	-
Se	1.3 ± 0.6	2.0 ± 0.4	0.74 ± 0.02	0.56 ± 0.01
Si	13.9 ± 0.1*	15.9 ± 0.3*	<204	-
Sm	2.85 ± 0.11	3.23 ± 0.18	0.0032 ± 0.0005	-
Sr	778 ± 31	972 ± 37	4.61 ± 0.62	-
Ta	0.424 ± 0.004	0.483 ± 0.004	-	-
Tb	0.39 ± 0.09	0.43 ± 0.15	-	-
Th	6.02 ± 0.05	10.5 ± 0.1	0.0042 ± 0.0017	0.0012 ± 0.0004
Ti	0.14 ± 0.01*	0.16 ± 0.01*	<1.2	5.4
U	3.36 ± 0.03	4.40 ± 0.05	0.030 ± 0.008	0.035 ± 0.001
V	90 ± 15	74 ± 14	0.28 ± 0.05	<0.055
W	1.4 ± 0.5	1.4 ± 0.6	-	-
Y	10.6 ± 1.0	14.2 ± 1.0	<1.0	-
Yb	1.14 ± 0.03	1.56 ± 0.03	-	-
Zn	37.9 ± 2.3	68.7 ± 3.3	4.33 ± 0.20	-

*Percent

Elemental abundances in products from run CS-62 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.07 ± 0.05*	3.84 ± 0.08*	17.9 ± 0.4	-
As	27.8 ± 1.2	39.6 ± 3.1	10.8 ± 0.5	6.93 ± 1.23
Ba	531 ± 16	596 ± 13	1.0 ± 0.1	-
C (org)	13.8 ± 1.4*	5.05 ± 0.79*	84.7 ± 8.5*	0.36 ± .01*
C (inor)	5.19 ± 0.52*	5.49 ± 0.45*	-	0.62 ± 0.01*
Ca	11.5 ± 0.1*	14.2 ± 0.6*	-	6 ± 1
Cd	0.67 ± 0.16	0.53 ± 0.03	<0.014	0.0058 ± 0.0048
Ce	36.6 ± 0.6	39.0 ± 0.7	0.047 ± 0.005	0.004 ± 0.001
Cl	-	-	4.7 ± 0.2	353 ± 3
Co	2.14 ± 0.17	~~3.04 ± 0.18~~	1.94 ± 0.01	0.421 ± 0.003
Cr	29.6 ± 0.5	22.9 ± 0.6	5.16 ± 0.05	0.57 ± 0.01
Cs	4.32 ± 0.13	4.18 ± 0.14	-	-
Cu	29.7 ± 2.6	41.4 ± 4.2	1.7 ± 0.5	<0.09
Dy	1.92 ± 0.07	2.08 ± 0.08	0.0039 ± 0.0005	-
Eu	0.531 ± 0.010	0.591 ± 0.010	0.0005 ± 0.0001	<0.0002
Fe	1.64 ± 0.05*	2.00 ± 0.07*	162 ± 8	15.3 ± 1.4
Ga	6.8 ± 1.2	8.4 ± 0.8	0.078 ± 0.021	0.06 ± 0.04
Ge	<1.5	<1.8	<0.48	<0.06
H	1.84 ± 0.18*	0.21 ± 0.01*	12.0 ± 1.2*	-
Hf	1.45 ± 0.15	1.72 ± 0.05	-	-
Hg	0.073 ± 0.012	0.036 ± 0.020	<0.079	0.049 ± 0.012
K	1.30 ± 0.02*	1.38 ± 0.09*	-	<4
La	18.6 ± 0.4	19.8 ± 0.5	0.022 ± 0.002	0.053 ± 0.006
Lu	0.15 ± 0.02	0.16 ± 0.02	-	-
Mg	3.65 ± 0.07*	4.45 ± 0.35*	27.3 ± 1.9	<9
Mn	283 ± 6	335 ± 20	1.29 ± 0.01	0.049 ± 0.007
Mo	20.1 ± 1.6	24.4 ± 1.9	0.32 ± 0.03	0.10 ± 0.01
N	0.63 ± 0.06*	0.49 ± 0.05*	2.09 ± 0.21*	1.45 ± 0.01*
Na	1.46 ± 0.04*	1.91 ± 0.17*	48.2 ± 0.4	326 ± 2
Nd	16 ± 2	15 ± 2	-	-
Ni	17.6 ± 3.4	23.6 ± 2.1	10.6 ± 0.7	10.7 ± 0.2
Pb	18.5 ± 1.8	25.6 ± 1.8	<1.6	<0.24
Rb	61.4 ± 2.5	70.1 ± 2.4	<0.72	0.15 ± 0.06
S	0.62 ± 0.06*	0.57 ± 0.10*	0.62 ± 0.06*	0.85 ± 0.02*
Sb	1.55 ± 0.12	1.94 ± 0.13	0.019 ± 0.001	0.104 ± 0.001
Sc	5.16 ± 0.14	5.23 ± 0.14	0.0034 ± 0.0001	-
Se	1.5 ± 0.6	2.3 ± 0.4	0.74 ± 0.01	0.47 ± 0.01
Si	12.9 ± 0.1*	15.4 ± 0.4*	<152	-
Sm	2.56 ± 0.12	2.79 ± 0.13	0.0028 ± 0.0004	-
Sr	791 ± 31	992 ± 29	1.41 ± 0.62	<0.12
Ta	0.354 ± 0.004	0.401 ± 0.004	0.06 ± 0.04	-
Tb	0.34 ± 0.09	0.33 ± 0.08	-	-
Th	5.45 ± 0.05	5.22 ± 0.05	0.0038 ± 0.0009	<0.18
Ti	0.12 ± 0.01*	0.15 ± 0.01*	<0.8	<0.60
U	4.29 ± 0.04	4.67 ± 0.04	0.014 ± 0.003	0.036 ± 0.001
V	87 ± 16	117 ± 16	0.55 ± 0.07	<0.057
W	1.1 ± 0.4	1.0 ± 0.4	-	0.05 ± 0.01
Y	7.8 ± 1.0	13.0 ± 0.6	<1.0	<0.15
Yb	1.24 ± 0.03	1.21 ± 0.03	0.003 ± 0.001	0.0011 ± 0.0006
Zn	52.7 ± 2.2	63.2 ± 2.6	4.06 ± 0.13	1.14 ± 0.05

*Percent

Elemental abundances in products from run [illegible]S-63 (ppm)

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	7.3[illegible] ± 0.08*	7.83 ± 0.38*	3.3 ± 0.2	-
As	[illegible] ± 1.2	35.2 ± 2.4	0.481 ± 0.003	1.83 ± 0.07
Ba	376 ± 16	388 ± 11	0.42 ± 0.05	-
C (org)	9.79 ± 0.[illegible]8*	6.50 ± 0.11*	83.8 ± 8.4*	0.17 ± 0.01*
(inor)	0.20 ± 0.02*	0.09 ± 0.01*	-	0.22 ± 0.01*
Ca	0.51 ± 0.01*	0.58 ± 0.02*	-	14 ± 1
Cd	0.67 ± 0.17	0.35 ± 0.13	<0.020	0.0065 ± 0.0008
Ce	79.4 ± 1.1	90.0 ± 1.5	-	0.014 ± 0.006
Cl	-	-	17.5 ± 0.2	387 ± 6
Co	24.4 ± 0.14	26.6 ± 0.6	0.0152 ± 0.0[illegible]	0.027 ± 0.001
Cr	82.4 ± 1.2	89.4 ± 2.3	0.14 ± 0.01	0.09 ± 0.01
Cs	7.13 ± 0.20	7.96 ± 0.22	-	0.081 ± 0.001
Cu	79.0 ± 3.2	87.0 ± 3.5	<0.75	0.35 ± 0.08
Dy	5.11 ± 0.08	6.64 ± 0.08	-	-
Eu	1.50 ± 0.02	1.67 ± 0.02	<0.00007	<0.0002
Fe	4.66 ± 0.15*	5.13 ± 0.06*	5.4 ± 1.2	2.73 ± 0.16
Ga	16.0 ± 1.4	18.2 ± 1.4	0.057 ± 0.002	0.06 ± 0.04
Ge	2.0 ± 1.0	1.8 ± 1.0	<0.48	0.05 ± 0.04
H	1.29 ± 0.13*	0.34 ± 0.02*	10.6 ± 1.1*	-
Hf	4.83 ± 0.09	5.31 ± 0.09	-	0.0048 ± 0.0007
Hg	0.138 ± 0.010	0.074 ± 0.009	<0.061	0.080 ± 0.005
K	3.12 ± 0.03*	3.36 ± 0.04*	5.2 ± 0.8	163 ± 8
La	34.5 ± 0.8	38.2 ± 0.8	0.00020 ± 0.00009	0.008 ± 0.002
Lu	0.48 ± 0.03	0.45 ± 0.03	-	-
Mg	1.14 ± 0.05*	1.22 ± 0.05*	4.9 ± 1.3	29 ± 7
Mn	195 ± 4	2[illegible] ± 4	0.141 ± 0.002	<0.02
Mo	114 ± 10	126 ± 10	0.036 ± 0.006	2.84 ± 0.05
N	0.53 ± 0.05*	0.33 ± 0.05*	0.74 ± 0.07*	1.13 ± 0.03*
Na	0.39 ± 0.01*	0.42 ± 0.01*	0.68 ± 0.01	193 ± 2
Nd	35 ± 3	42 ± 3	-	-
Ni	80.8 ± 4.6	91.4 ± 4.8	2.29 ± 0.62	1.01 ± 0.08
Pb	25.5 ± 1.8	29.8 ± 2.0	1.[illegible]	<0.24
Rb	131 ± 5	146 ± 5	<0.69	1.21 ± 0.06
S	3.20 ± 0.32*	2.49 ± 0.04*	1.93 ± 0.18*	1.15 ± 0.07*
Sb	4.00 ± 0.25	3.59 ± 0.23	0.0072 ± 0.0002	0.920 ± 0.005
Sc	14.5 ± 0.4	15.7 ± 0.4	-	-
Se	2.7 ± 0.6	2.0 ± 0.6	1.05 ± 0.01	0.44 ± 0.02
Si	26.5 ± 0.1*	28.0 ± 0.6*	<96	4.22[a]
Sm	6.71 ± 0.70	7.50 ± 0.75	-	-
Sr	73.5 ± 2.9	84.0 ± 3.4	<0.90	0.37 ± 0.11
Ta	0.878 ± 0.007	0.974 ± 0.010	-	-
Tb	0.93 ± 0.15	1.05 ± 0.16	-	-
Th	10.5 ± 0.1	11.4 ± 0.1	<1.4	0.17 ± 0.12
Ti	0.42 ± 0.04*	0.46 ± 0.01*	<0.5	0.69 ± 0.40
U	28.8 ± 0.2	31.0 ± 0.6	0.0010 ± 0.0003	0.73 ± 0.01
V	156 ± 18	176 ± 17	1.60 ± 0.02	<0.06
W	<3.6	<3.3	-	-
Y	32.1 ± 1.2	36.0 ± 1.4	<1.0	<0.15
Yb	3.30 ± 0.05	3.60 ± 0.05	-	-
Zn	39.4 ± 2.2	45.8 ± 2.2	7.05 ± 0.10	0.92 ± 0.02

*Percent

[a] Inductively-coupled plasma emission spectroscopy by LLL.

Table 131

Elemental abundances in products from run CS-04 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.76 ± 0.06*	4.87 ± 0.07*	4.6 ± 0.2	-
As	46.5 ± 1.9	74.3 ± 4.4	4.31 ± 0.34	3.79 ± 0.43
Ba	256 ± 14	444 ± 33	0.58 ± 0.06	-
C (org)	26.2 ± 2.6*	9.13 ± 0.45*	84.2 ± 8.4*	0.34 ± 0.01*
C (inor)	2.92 ± 0.24*	2.00 ± 0.25*	-	0.56 ± 0.01*
Ca	5.37 ± 0.03*	8.04 ± 0.09*	-	14 ± 1
Cd	1.04 ± 0.10	1.02 ± 0.17	<0.014	0.0012 ± 0.0004
Ce	36.1 ± 0.7	44.7 ± 2.5	0.019 ± 0.004	0.014 ± 0.004
Cl	-	-	4.5 ± 0.1	372 ± 5
Co	13.4 ± 0.2	18.1 ± 0.5	2.24 ± 0.01	0.315 ± 0.003
Cr	35.2 ± 0.7	50.5 ± 0.8	0.20 ± 0.01	0.028 ± 0.005
Cs	3.43 ± 0.12	4.93 ± 0.29	-	0.042 ± 0.001
Cu	50.4 ± 2.4	74.8 ± 2.3	<0.75	0.11 ± 0.08
Dy	1.85 ± 0.08	2.46 ± 0.08	0.0014 ± 0.0002	-
Eu	0.540 ± 0.010	0.725 ± 0.012	-	<0.0001
Fe	2.16 ± 0.17*	2.99 ± 0.04*	68.5 ± 3.4	2.02 ± 0.14
Ga	7.2 ± 1.0	10.9 ± 1.0	0.048 ± 0.028	0.05 ± 0.04
Ge	2.0 ± 1.0	4.2 ± 0.9	<0.45	0.10 ± 0.04
H	3.96 ± 0.40*	0.24 ± 0.05*	12.0 ± 1.2*	-
Hf	1.37 ± 0.05	1.98 ± 0.06	-	0.0013 ± 0.0003
Hg	0.273 ± 0.081	0.046 ± 0.021	0.042 ± 0.005	0.196 ± 0.005
K	1.12 ± 0.02*	1.51 ± 0.04*	-	<4
La	19.7 ± 1.1	25.7 ± 0.9	0.0090 ± 0.0028	<0.017
Lu	0.11 ± 0.02	0.18 ± 0.02	-	-
Mg	2.96 ± 0.06*	3.86 ± 0.11*	6.5 ± 0.6	<15
Mn	215 ± 4	333 ± 14	0.156 ± 0.001	<0.06
Mo	37.7 ± 2.7	51.5 ± 3.7	0.20 ± 0.11	0.32 ± 0.01
N	1.05 ± 0.11*	0.62 ± 0.08*	1.76 ± 0.19*	1.39 ± 0.05*
Na	2.43 ± 0.02*	3.36 ± 0.06*	34.6 ± 0.4	1249 ± 9
Nd	17 ± 2	23 ± 2	-	-
Ni	26.3 ± 3.2	38.4 ± 2.7	4.33 ± 0.64	2.33 ± 0.11
Pb	36.6 ± 1.6	55.5 ± 1.1	<1.6	<0.24
Rb	64.9 ± 2.6	91.3 ± 2.9	<0.69	0.28 ± 0.06
S	1.04 ± 0.10*	1.43 ± 0.18*	0.83 ± 0.08*	0.16 ± 0.01*
Sb	2.53 ± 0.17	3.53 ± 0.22	0.011 ± 0.002	0.150 ± 0.001
Sc	5.26 ± 0.14	7.55 ± 0.21	[illegible]	-
Se	2.5 ± 0.6	4.8 ± 0.4	[illegible]	0.28 ± 0.01
Si	13.8 ± 0.1*	18.1 ± 0.3*	<96	-
Sm	2.48 ± 0.14	3.37 ± 0.18	0.0015 ± 0.0002	-
Sr	331 ± 13	541 ± 16	<0.87	<0.12
Ta	0.413 ± 0.004	0.559 ± 0.007	-	-
Tb	0.29 ± 0.07	0.38 ± 0.10	-	-
Th	4.80 ± 0.05	7.11 ± 0.33	<1.3	<0.18
Ti	0.14 ± 0.03*	0.19 ± 0.02*	<0.4	<0.57
U	5.05 ± 0.05	7.00 ± 0.33	<2.3	0.043 ± 0.001
V	132 ± 15	214 ± 21	0.75 ± 0.01	<0.063
W	2.6 ± 0.8	2.4 ± 0.9	-	-
Y	3.8 ± 1.0	13.1 ± 0.7	<1.0	0.12 ± 0.10
Yb	0.997 ± 0.031	1.43 ± 0.05	-	-
Zn	59.5 ± 2.8	101 ± 3	0.69 ± 0.09	0.13 ± 0.04

*Percent

Table 132

Elemental abundances in products from run CS-[illegible]5 (ppm).

	Raw oil .Shale	Spent oil shale	Shale oil	Retort water
Al	4.16 ± 0.06*	4.52 ± 0.08*	<0.2	-
As	13.3 ± 0.8	17.4 ± 1.0	1.07 ± 0.34	2.48 ± 0.12
Ba	101 ± 11	114 ± 9	0.44 ± 0.05	-
C (org)	13.0 ± 1.3*	7.32 ± 0.62*	81.2 ± 8.1*	0.53 ± 0.01*
C (inor)	4.33 ± 0.43*	4.79 ± 0.29*	-	0.16 ± 0.01*
Ca	12.9 ± 0.1*	14.8 ± 0.3*	-	4 ± 1
Cd	-	11.7 ± 2.6	<0.014	0.0089 ± 0.0002
Ce	43.1 ± 0.9	49.8 ± 1.3	-	<0.011
Cl	-	-	20.1 ± 0.1	346 ± 3
Co	5.22 ± 0.15	5.80 ± 0.16	0.096 ± 0.005	0.020 ± 0.001
Cr	326 ± 3	374 ± 7	0.27 ± 0.02	0.009 ± 0.006
Cs	2.02 ± 0.13	2.68 ± 0.14	-	0.005 ± 0.001
Cu	56.0 ± 2.8	70.9 ± 3.2	<1.0	0.19 ± 0.06
Dy	3.91 ± 0.06	4.57 ± 0.15	0.014 ± 0.003	-
Eu	1.08 ± 0.02	1.25 ± 0.02	-	<0.0002
Fe	2.05 ± 0.02*	2.33 ± 0.02*	21.4 ± 3.9	2.02 ± 0.12
Ga	8.4 ± 1.2	9.4 ± 1.4	0.13 ± 0.01	0.07 ± 0.04
Ge	<1.5	<1.8	<0.57	0.15 ± 0.04
H	1.78 ± 0.18*	0.30 ± 0.01*	11.1 ± 1.1*	-
Hf	2.83 ± 0.08	3.29 ± 0.11	-	-
Hg	0.101 ± 0.015	0.029 ± 0.007	0.059 ± 0.001	0.320 ± 0.025
K	0.76 ± 0.01*	0.86 ± 0.01*	1.6 ± 0.4	60 ± 3
La	24.6 ± 1.1	27.3 ± 0.7	0.0043 ± 0.0029	0.003 ± 0.001
Lu	0.40 ± 0.02	0.42 ± 0.04	-	-
Mg	2.23 ± 0.05*	2.64 ± 0.06*	6.5 ± 0.8	24 ± 9
Mn	110 ± 2	133 ± 5	0.117 ± 0.0[illegible]	<0.02
Mo	52.5 ± 3.5	63.2 ± 4.2	0.17 ± 0.03	0.29 ± 0.02
N	0.62 ± 0.06*	0.48 ± 0.06*	1.26 ± 0.13*	0.82 ± 0.06*
Na	0.12 ± 0.03*	0.14 ± 0.03*	11.0 ± 0.1	197 ± 2
Nd	23 ± 3	32 ± 3	-	-
Ni	127 ± 5	153 ± 5	8.92 ± 0.62	2.40 ± 0.13
Pb	3.4 ± 1.6	6.9 ± 2.1	<1.8	<0.24
Rb	39.0 ± 1.6	47.3 ± 1.9	<0.75	0.34 ± 0.06
S	1.36 ± 0.14*	0.78 ± 0.12*	7.11 ± 0.71*	0.73 ± 0.02*
Sb	1.74 ± 0.13	2.21 ± 0.16	0.009 ± 0.001	0.357 ± 0.002
Sc	10.5 ± 0.3	12.0 ± 0.3	0.00036 ± 0.00007	-
Se	16.5 ± 0.8	19.9 ± 2.1	14.3 ± 0.1	5.34 ± 0.03
Si	12.3 ± 0.1*	13.8 ± 0.2*	<121	8.43[a]
Sm	3.80 ± 0.67	4.30 ± 0.79	0.0005 ± 0.0001	0.0015 ± 0.0008
Sr	396 ± 15	474 ± 18	0.14 ± 0.04	0.12 ± 0.08
Ta	0.484 ± 0.005	0.577 ± 0.022	-	0.013 ± 0.001
Tb	0.55 ± 0.08	0.68 ± 0.02	-	-
Th	5.37 ± 0.06	5.98 ± 0.10	<1.5	<0.18
Ti	0.20 ± 0.01*	0.21 ± 0.01*	<1.1	<0.60
U	27.7 ± 0.2	32.8 ± 0.3	0.010 ± 0.001	0.285 ± 0.003
V	149 ± 15	167 ± 14	4.20 ± 0.04	<0.038
W	<4.5	<2.6	-	-
Y	32.1 ± 1.3	39.5 ± 1.5	<1.1	<0.15
Yb	2.56 ± 0.05	3.08 ± 0.09	-	-
Zn	316 ± 12	407 ± 16	1.94 ± 0.08	0.85 ± 0.03

*Percent

[a] Inductively-coupled plasma emission spectroscopy by LLL.

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Table 133

Elemental abundances in products from run CS-66 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.43 ± 0.05*	4.75 ± 0.13*	36.6 ± 1.6	-
As	40.7 ± 1.6	54.8 ± 4.6	9.83 ± 0.49	12.0 ± 1.6
Ba	422 ± 19	570 ± 21	2.1 ± 0.3	0.23 ± 0.18
C (org)	13.4 ± 1.3*	3.82 ± 1.07*	84.4 ± 8.4*	0.43 ± 0.01*
C (inor)	4.75 ± 0.48*	3.84 ± 0.22*	-	0.86 ± 0.01*
Ca	10.2 ± 0.1*	11.7 ± 0.3*	78 ± 24	23 ± 1
Cd	0.75 ± 0.02	0.71 ± 0.15	-	0.004 ± 0.006
Ce	38.7 ± 0.7	51.0 ± 0.8	0.078 ± 0.006	0.008 ± 0.003
Cl	-	-	4.0 ± 0.4	271 ± 5
Co	8.60 ± 0.21	10.9 ± 0.2	2.82 ± 0.02	0.643 ± 0.004
Cr	30.4 ± 0.6	41.0 ± 0.8	0.27 ± 0.02	0.038 ± 0.006
Cs	4.88 ± 0.16	6.83 ± 0.19	-	0.045 ± 0.001
Cu	35.9 ± 2.6	45.5 ± 3.0	<0.72	0.19 ± 0.11
Dy	2.11 ± 0.07	2.67 ± 0.10	0.010 ± 0.001	-
Eu	0.538 ± 0.011	0.746 ± 0.011	0.0018 ± 0.0006	<0.0001
Fe	1.77 ± 0.05*	2.45 ± 0.01*	62.9 ± 3.1	1.98 ± 0.25
Ga	7.1 ± 1.2	10.9 ± 1.4	<0.48	<0.06
Ge	<1.5	<1.8	<0.48	<0.06
H	2.19 ± 0.22*	0.23 ± 0.05*	11.5 ± 1.2*	-
Hf	1.56 ± 0.06	2.24 ± 0.11	-	0.0065 ± 0.0004
Hg	0.093 ± 0.013	0.015 ± 0.006	<0.082	0.160 ± 0.014
K	1.30 ± 0.02*	1.69 ± 0.04*	27 ± 10	54 ± 5
La	18.8 ± 0.5	24.7 ± 0.7	0.10 ± 0.01	0.015 ± 0.011
Lu	0.13 ± 0.02	0.18 ± 0.02	-	-
Mg	3.43 ± 0.07*	4.49 ± 0.15*	67.4 ± 3.7	<15
Mn	298 ± 6	372 ± 10	0.792 ± 0.006	<0.06
Mo	23.2 ± 1.9	29.0 ± 2.3	<1.5	1.34 ± 0.03
N	0.57 ± 0.06*	0.30 ± 0.01*	1.93 ± 0.19*	1.65 ± 0.08*
Na	1.73 ± 0.01*	2.37 ± 0.10*	260 ± 3	1594 ± 16
Nd	17 ± 2	21 ± 2	-	-
Ni	19.1 ± 3.4	24.1 ± 3.6	7.72 ± 0.70	3.14 ± 0.84
Pb	21.2 ± 1.8	29.8 ± 2.0	<1.6	<0.24
Rb	62.5 ± 2.5	81.2 ± 3.2	<0.69	0.66 ± 0.09
S	0.54 ± 0.05*	0.61 ± 0.02*	0.56 ± 0.06*	0.10 ± 0.01*
Sb	2.07 ± 0.17	2.28 ± 0.18	0.030 ± 0.002	0.252 ± 0.001
Sc	5.11 ± 0.14	6.83 ± 0.21	0.0040 ± 0.0001	-
Se	1.9 ± 0.6	2.9 ± 0.6	0.93 ± 0.02	0.41 ± 0.01
Si	13.3 ± 0.1*	17.7 ± 0.3*	<226	-
Sm	2.63 ± 0.12	3.46 ± 0.15	0.014 ± 0.002	-
Sr	716 ± 28	860 ± 33	<0.87	0.33 ± 0.08
Ta	0.412 ± 0.005	0.565 ± 0.014	-	-
Tb	0.31 ± 0.02	0.42 ± 0.03	-	-
Th	5.52 ± 0.05	7.26 ± 0.11	0.007 ± 0.002	0.0074 ± 0.0004
Ti	0.12 ± 0.02*	0.18 ± 0.02*	<2.2	<0.60
U	4.36 ± 0.04	5.58 ± 0.05	<2.3	0.123 ± 0.002
V	72 ± 15	123 ± 14	1.09 ± 0.03	<0.063
W	1.1 ± 0.3	2.1 ± 0.4	-	-
Y	8.5 ± 1.0	15.1 ± 1.0	<1.0	<0.15
Yb	1.11 ± 0.03	1.51 ± 0.06	-	0.0021 ± 0.0004

Table 134

Elemental abundances in products from run CS-67 (ppm)

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.41 ± 0.06*	4.85 ± 0.13*	9.7 ± 0.3	-
As	42.3 ± 1.7	73.4 ± 2.9	4.12 ± .34	3.43 ± 0.31
Ba	268 ± 14	406 ± 49	0.5 ± 0.1	0.14 ± 0.12
C (org)	26.2 ± 2.6*	9.35 ± 0.49*	85.0 ± 8.5*	0.43 ± 0.01*
C (inor)	3.05 ± 0.31*	2.65 ± 0.25*	-	0.55 ± 0.01*
Ca	5.77 ± 0.03*	8.25 ± 0.18*	-	6 ± 1
Cd	1.20 ± 0.06	1.43 ± 0.35	<0.014	0.00069 ± 0.00045
Ce	35.7 ± 0.8	48.2 ± 0.8	0.011 ± 0.004	<0.011
Cl	-	-	1.5 ± 0.1	326 ± 4
Co	13.3 ± 0.3	18.1 ± 0.3	1.98 ± 0.01	0.213 ± 0.002
Cr	33.3 ± 0.7	47.8 ± 1.5	0.22 ± 0.01	0.011 ± 0.005
Cs	3.10 ± 0.14	4.55 ± 0.18	-	0.066 ± 0.001
Cu	51.2 ± 2.4	73.5 ± 3.2	<0.72	<0.09
Dy	1.71 ± 0.08	2.12 ± 0.40	0.0009 ± 0.0002	-
Eu	0.484 ± 0.011	0.685 ± 0.013	-	<0.0002
Fe	1.94 ± 0.16*	2.90 ± 0.08*	60.0 ± 3.0	1.21 ± 0.14
Ga	6.5 ± 1.0	11.0 ± 1.4	0.034 ± 0.008	<0.06
Ge	1.6 ± 1.0	3.3 ± 1.2	<0.48	0.06 ± 0.04
H	3.74 ± 0.37*	0.34 ± 0.02*	11.9 ± 1.2*	-
Hf	1.33 ± 0.06	1.93 ± 0.08	-	0.0014 ± 0.0003
Hg	0.308 ± 0.081	0.043 ± 0.016	0.059 ± 0.004	0.095 ± 0.009
K	1.01 ± 0.02*	1.49 ± 0.02*	5.0 ± 1.6	5 ± 3
La	18.0 ± 0.5	24.2 ± 0.6	0.0064 ± 0.0013	0.032 ± 0.002
Lu	0.10 ± 0.02	0.16 ± 0.05	-	-
Mg	2.87 ± 0.06*	4.01 ± 0.07*	8.2 ± 1.5	<17
Mn	242 ± 5	329 ± 7	0.156 ± 0.002	<0.10
Mo	31.8 ± 2.5	45.6 ± 3.5	0.15 ± 0.04	0.53 ± 0.02
N	0.91 ± 0.09*	0.63 ± 0.07*	1.93 ± 0.19*	1.13 ± 0.03*
Na	2.36 ± 0.06*	3.34 ± 0.02*	51.5 ± 0.5	1360 ± 12
Nd	15 ± 2	17 ± 3	-	-
Ni	24.2 ± 3.2	35.8 ± 4.0	4.12 ± 0.62	1.28 ± 0.08
Pb	35.7 ± 1.6	54.4 ± 2.2	<1.6	<0.24
Rb	56.6 ± 2.3	89.4 ± 3.6	<0.69	0.29 ± 0.06
S	2.54 ± 0.25*	1.78 ± 0.21*	0.82 ± 0.08*	0.14 ± 0.01*
Sb	2.50 ± 0.19	3.79 ± 0.27	0.005 ± 0.001	0.148 ± 0.001
Sc	5.30 ± 0.14	7.46 ± 0.21	0.00089 ± 0.00010	-
Se	2.4 ± 0.6	4.3 ± 0.6	0.81 ± 0.01	1.25 ± 0.06
Si	12.9 ± 0.1*	18.2 ± 0.2*	<79	-
Sm	2.29 ± 0.12	3.13 ± 0.16	0.0009 ± 0.0001	0.0007 ± 0.0005
Sr	350 ± 1.4	541 ± 21	<0.87	0.10 ± 0.08
Ta	0.388 ± 0.005	0.557 ± 0.006	-	-
Tb	0.25 ± 0.07	0.33 ± 0.10	-	-
Th	4.66 ± 0.05	6.41 ± 0.17	<1.4	0.0008 ± 0.0004
Ti	0.11 ± 0.05*	0.19 ± 0.02*	<0.5	<0.60
U	4.79 ± 0.05	6.32 ± 0.09	<2.3	0.046 ± 0.002
V	166 ± 18	255 ± 19	0.60 ± 0.04	<0.072
W	1.4 ± 0.4	2.9 ± 0.5	-	-
Y	3.6 ± 0.8	12.3 ± 1.0	<1.0	<0.15
Yb	0.963 ± 0.033	1.39 ± 0.07	-	-
Zn	69.3 ± 2.8	98.6 ± 7.4	0.69 ± 0.11	0.09 ± 0.04

*Percent

Table 135

Elemental abundances in products from run CS-68 (ppm).

	Raw oil shale	Spent shale	Shale oil	Retort water
Al	3.90 ± 0.06*	4.43 ± 0.09*	18.0 ± 0.7	-
As	41.9 ± 1.7	46.3 ± 5.9	14.2 ± 0.7	15.3 ± 2.1
Ba	463 ± 19	570 ± 40	1.4 ± 0.2	0.48 ± 0.11
C (org)	11.3 ± 1.1*	4.27 ± 0.52*	84.3 ± 8.4*	0.37 ± 0.01*
C (inor)	4.77 ± 0.48*	4.78 ± 0.41*	-	0.76 ± 0.01*
Ca	9.92 ± 0.05*	11.3 ± 0.5*	-	20 ± 7
Cd	0.75 ± 0.08	0.63 ± 0.16	<0.014	0.0024 ± 0.0029
Ce	43.2 ± 0.7	48.5 ± 2.6	0.058 ± 0.006	0.010 ± 0.004
Cl	-	-	2.4 ± 0.2	321 ± 5
Co	9.45 ± 0.21	10.[illegible]	3.07 ± 0.02	0.614 ± 0.006
Cr	33.8 ± 0.6	39.[illegible] ± 1.1	0.16 ± 0.01	0.050 ± 0.007
Cs	5.46 ± 0.17	6.70 ± 0.38	-	0.035 ± 0.001
Cu	34.9 ± 2.6	42.1 ± 2.8	<0.78	0.15 ± 0.08
Dy	2.26 ± 0.08	2.56 ± 0.09	0.007 ± 0.001	-
Eu	0.651 ± 0.012	0.741 ± 0.016	0.0012 ± 0.0003	0.0002 ± 0.0001
Fe	2.07 ± 0.06*	2.32 ± 0.07*	75.7 ± 3.7	3.40 ± 0.20
Ga	7.8 ± 1.2	10.[illegible] ± 0.7	<0.51	0.07 ± 0.04
Ge	<1.5	<1.5	<0.48	0.13 ± 0.04
H	1.37 ± 0.14*	0.28 ± 0.06*	11.8 ± 1.2*	-
Hf	1.70 ± 0.06	2.14 ± 0.13	-	0.0033 ± 0.0004
Hg	0.060 ± 0.014	0.027 ± 0.007	0.039 ± 0.004	0.150 ± 0.014
K	1.48 ± 0.02*	1.64 ± 0.10*	-	144 ± 3
La	21.1 ± 0.7	24.[illegible] ± 0.5	0.043 ± 0.005	-
Lu	0.18 ± 0.02	0.19 ± 0.02	-	-
Mg	3.63 ± 0.07*	4.25 ± 0.14*	42.7 ± 2.8	<19
Mn	306 ± 6	356 ± 10	0.520 ± 0.006	<0.07
Mo	23.9 ± 2.0	27.[illegible] ± 2.1	-	1.39 ± 0.04
N	0.56 ± 0.06*	0.[illegible] ± 0.04*	2.00 ± 0.20*	1.68 ± 0.07*
Na	1.95 ± 0.01*	2.[illegible] ± 0.07*	137 ± 2	1780 ± 10
Nd	17 ± 2	[illegible] ± 3	-	-
Ni	20.5 ± 3.6	24.[illegible] ± 3.8	8.04 ± 0.74	3.73 ± 0.18
Pb	20.6 ± 1.8	27.[illegible] ± 2.4	<1.6	<0.24
Rb	65.0 ± 2.6	76.1 ± 2.9	<0.69	0.61 ± 0.06
S	0.46 ± 0.05*	0.37 ± 0.03*	0.66 ± 0.07*	0.12 ± 0.01*
Sb	1.99 ± 0.16	2.24 ± 0.17	0.016 ± 0.002	0.253 ± 0.002
Sc	5.82 ± 0.16	6.67 ± 0.18	0.0028 ± 0.0003	-
Se	1.8 ± 0.6	2.5 ± 0.6	0.94 ± 0.02	0.71 ± 0.04
Si	14.8 ± 0.1*	16.[illegible] ± 0.3*	<93	-
Sm	2.93 ± 0.13	3.35 ± 0.14	0.0056 ± 0.0009	0.0017 ± 0.0007
Sr	681 ± 27	839 ± 37	<0.87	0.21 ± 0.08
Ta	0.477 ± 0.005	0.540 ± 0.019	-	0.051 ± 0.045
Tb	0.33 ± 0.10	0.40 ± 0.10	-	-
Th	6.54 ± 0.06	7.34 ± 0.67	0.004 ± 0.002	0.0046 ± 0.0005
Ti	0.17 ± 0.01*	0.18 ± 0.01*	<1.0	0.62 ± 0.40
U	4.76 ± 0.04	5.10 ± 0.34	<2.3	0.111 ± 0.003
V	124 ± 16	122 ± 14	1.02 ± 0.05	0.19 ± 0.07
W	1.8 ± 0.4	1.7 ± 0.5	-	-
Y	11.1 ± 1.0	14.4 ± 1.0	<1.0	<0.15
Yb	1.29 ± 0.03	1.50 ± 0.06	-	-
Zn	60.4 ± 2.4	72.9 ± 2.8	0.83 ± 0.16	0.15 ± 0.03

*Percent

Table 136

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Elemental abundances in products from run CS-69 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.67 ± 0.06*	5.35 ± 0.30*	19.2 ± 0.5	-
As	40.7 ± 1.6	63.8 ± 4.6	8.81 ± 0.44	6.27 ± 0.92
Ba	463 ± 12	690 ± 44	1.7 ± 0.1	-
C (org)	12.7 ± 1.3*	2.59 ± 0.60*	82.6 ± 6.3*	0.28 ± 0.01*
C (inor)	4.86 ± 0.49*	0.78 ± 0.09*	-	1.48 ± 0.01*
Ca	8.03 ± 0.04*	14.4 ± 0.3*	-	19 ± 1
Cd	0.89 ± 0.03	0.74 ± 0.28	<0.014	0.0012 ± 0.0008
Ce	40.4 ± 0.7	58.9 ± 3.3	0.019 ± 0.006	-
Cl	-	-	2.3 ± 0.1	328 ± 5
Co	9.35 ± 0.18	12.2 ± 0.8	2.85 ± 0.02	0.448 ± 0.005
Cr	34.4 ± 0.6	47.2 ± 5.0	0.15 ± 0.01	0.061 ± 0.006
Cs	5.30 ± 0.14	8.13 ± 0.82	-	0.043 ± 0.001
Cu	36.1 ± 2.6	51.1 ± 2.4	<0.72	<0.09
Dy	2.26 ± 0.08	3.11 ± 0.22	0.0049 ± 0.0002	-
Eu	0.593 ± 0.009	0.884 ± 0.040	0.00035 ± 0.00024	<0.0001
Fe	1.93 ± 0.04*	2.81 ± 0.13*	53.6 ± 2.6	4.51 ± 0.56
Ga	8.7 ± 1.2	11.9 ± 1.4	0.08 ± 0.01	<0.06
Ge	<1.5	<1.8	<0.45	<0.06
H	1.76 ± 0.19*	0.01 ± 0.001*	11.3 ± 1.1*	-
Hf	1.60 ± 0.05	2.48 ± 0.20	0.007 ± 0.006	0.0016 ± 0.0003
Hg	0.086 ± 0.020	0.016 ± 0.010	0.054 ± 0.001	0.103 ± 0.013
K	1.37 ± 0.18*	2.02 ± 0.08*	7.2 ± 1.0	37 ± 3
La	20.6 ± 0.5	29.6 ± 1.5	0.017 ± 0.003	0.055 ± 0.003
Lu	0.15 ± 0.01	0.24 ± 0.02	-	-
Mg	3.50 ± 0.07*	5.10 ± 0.15*	30.3 ± 1.1	<22
Mn	297 ± 6	433 ± 15	0.411 ± 0.003	<0.05
Mo	28.6 ± 2.3	32.8 ± 2.3	0.38 ± 0.14	0.74 ± 0.02
N	0.57 ± 0.04*	0.015 ± 0.001*	1.92 ± 0.19*	2.97 ± 0.02*
Na	1.93 ± 0.02*	2.59 ± 0.17*	24.2 ± 0.3	1475 ± 10
Nd	15 ± 2	23 ± 3	-	-
Ni	20.3 ± 3.6	28.7 ± 4.2	6.65 ± 0.68	1.80 ± 0.82
Pb	23.3 ± 1.8	32.6 ± 8.1	<1.6	<0.24
Rb	62.1 ± 2.5	94.2 ± 5.2	<0.09	0.50 ± 0.06
S	0.49 ± 0.05*	0.36 ± 0.26*	0.67 ± 0.07*	0.05 ± 0.01*
Sb	2.00 ± 0.14	2.53 ± 0.14	0.017 ± 0.002	0.314 ± 0.002
Sc	5.56 ± 0.15	8.13 ± 0.49	0.0011 ± 0.0002	-
Se	2.3 ± 0.6	3.6 ± 0.8	0.84 ± 0.01	0.60 ± 0.06
Si	13.7 ± 0.1*	20.2 ± 0.9*	<141	11.8[a]
Sm	2.84 ± 0.13	4.13 ± 0.20	0.0021 ± 0.0002	0.0006 ± 0.0005
Sr	472 ± 26	1002 ± 55	0.61 ± 0.06	0.21 ± 0.08
Ta	0.438 ± 0.004	0.644 ± 0.038	-	-
Tb	0.37 ± 0.09	0.51 ± 0.14	-	-
Th	5.98 ± 0.05	8.80 ± 0.86	<1.4	0.0016 ± 0.0003
Ti	0.14 ± 0.02*	0.21 ± 0.03*	<0.6	0.67 ± 0.40
U	4.48 ± 0.04	6.49 ± 0.32	<2.3	0.075 ± 0.001
V	101 ± 13	141 ± 21	0.74 ± 0.01	0.07[a]
W	1.4 ± 0.5	1.8 ± 0.5	-	0.22 ± 0.04
Y	9.1 ± 1.0	19.6 ± 1.2	<1.0	< 0.15
Yb	1.23 ± 0.03	1.79 ± 0.08	-	0.0013 ± 0.0005
Zn	57.4 ± 2.3	88.7 ± 5.2	0.65 ± 0.15	0.10 ± 0.03

*Percent

[a] Inductively-coupled plasma emission spectroscopy by LLL.

Table 137

Elemental abundances in products from run CS-70 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.54 ± 0.06*	4.34 ± 0.10*	<0.4	-
As	44.7 ± 1.8	53.5 ± 2.5	7.92 ± 4.0	8.22 ± 1.29
Ba	488 ± 14	573 ± 16	-	0.57 ± 0.07
C (org)	14.79 ± 0.01*	3.99 ± 0.76*	84.1 ± 3.4*	0.42 ± 0.01*
C (inor)	4.86 ± 0.01*	4.18 ± 0.28*	-	0.79 ± 0.01*
Ca	11.0 ± 0.1*	12.6 ± 0.5*	-	24 ± 1
Cd	0.82 ± 0.20	0.74 ± 0.05	<0.014	0.0011 ± 0.0006
Ce	35.8 ± 0.6	47.4 ± 1.1	0.027 ± 0.005	0.0092 ± 0.0032
Cl	-	-	-	308 ± 4
Co	8.90 ± 0.17	11.0 ± 0.6	2.60 ± 0.02	0.469 ± 0.004
Cr	33.0 ± 0.6	43.4 ± 4.8	0.36 ± 0.02	0.055 ± 0.006
Cs	4.00 ± 0.12	5.92 ± 0.67	-	0.043 ± 0.001
Cu	33.8 ± 2.6	46.8 ± 1.4	<0.72	<0.09
Dy	2.00 ± 0.08	2.68 ± 0.08	-	-
Eu	0.554 ± 0.009	0.712 ± 0.020	-	<0.0001
Fe	1.87 ± 0.05*	2.40 ± 0.05*	63.2 ± 3.1	4.50 ± 0.22
Ga	7.8 ± 1.2	9.6 ± 1.4	<0.48	0.05 ± 0.04
Ge	1.2 ± 1.0	<1.8	<0.45	<0.06
H	2.07 ± 0.01*	0.24 ± 0.09*	12.2 ± 1.2*	-
Hf	1.41 ± 0.05	1.98 ± 0.05	-	0.0049 ± 0.0003
Hg	0.062 ± 0.005	0.0067 ± 0.0013	0.029 ± 0.010	0.098 ± 0.007
K	1.38 ± 0.02*	1.67 ± 0.06*	-	36 ± 3
La	18.6 ± 0.5	23.6 ± 1.0	0.040 ± 0.003	-
Lu	0.15 ± 0.01	0.18 ± 0.02	-	-
Mg	3.49 ± 0.07*	4.19 ± 0.20*	29.2 ± 2.0	<27
Mn	287 ± 6	360 ± 7	0.354 ± 0.003	<0.04
Mo	25.6 ± 2.1	33.4 ± 2.5	0.59 ± 0.12	0.65 ± 0.02
N	0.64 ± 0.01*	0.34 ± 0.10*	1.94 ± 0.19*	1.49 ± 0.02*
Na	1.69 ± 0.05*	3.30 ± 0.06*	124 ± 1	1283 ± 10
Nd	16 ± 1	19 ± 2	-	-
Ni	20.1 ± 3.4	24.3 ± 3.8	6.85 ± 0.68	2.02 ± 0.09
Pb	21.3 ± 1.8	28.6 ± 2.0	<1.5	<0.24
Rb	57.2 ± 2.3	73.2 ± 2.9	<0.69	0.50 ± 0.06
S	0.56 ± 0.01*	0.41 ± 0.09*	0.65 ± 0.07*	0.11 ± 0.01*
Sb	2.01 ± 0.14	2.59 ± 0.10	0.022 ± 0.002	0.158 ± 0.001
Sc	5.55 ± 0.15	6.68 ± 0.18	0.0019 ± 0.0002	-
Se	1.6 ± 0.6	2.7 ± 0.6	0.93 ± 0.01	0.57 ± 0.04
Si	13.1 ± 0.1*	16.5 ± 0.5*	<95	-
Sm	2.63 ± 0.13	3.38 ± 0.15	0.0020 ± 0.0005	-
Sr	733 ± 29	862 ± 37	<1.2	0.21 ± 0.08
Ta	0.394 ± 0.004	0.509 ± 0.006	-	-
Tb	0.32 ± 0.09	0.40 ± 0.10	-	-
Th	6.01 ± 0.05	7.40 ± 0.46	<1.3	0.0094 ± 0.0004
Ti	0.14 ± 0.03*	0.16 ± 0.01*	<1.2	0.81 ± 0.40
U	4.47 ± 0.04	5.41 ± 0.30	<2.3	0.082 ± 0.002
V	118 ± 16	123 ± 14	0.89 ± 0.02	<0.25
W	2.2 ± 0.6	1.9 ± 0.6	-	-
Y	8.7 ± 1.0	14.4 ± 1.0	<1.0	<0.15
Yb	1.21 ± 0.3	1.50 ± 0.06	-	0.0021 ± 0.0004
Zn	59.4 ± 2.4	77.5 ± 3.0	0.53 ± 0.13	0.26 ± 0.03

*Percent

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Table 138

Elemental abundances in products from run CS-71 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	2.96 ± 0.05*	3.71 ± 0.12*	2.0 ± 0.7	-
As	36.4 ± 1.8	41.8 ± 3.8	9.09 ± 0.06	4.61 ± 0.23
Ba	-	-	-	0.097 ± 0.073
C (org)	14.5*	3.94 ± 0.88*	84.5 ± 8.5	0.56 ± 0.01*
C (inor)	5.05*	4.79 ± 0.18*	-	0.53 ± 0.01*
Ca	11.9 ± 0.1*	14.2 ± 0.4	79 ± 12	15 ± 1
Cd	-	-	<0.014	-
Ce	-	-	0.041 ± 0.005	0.0037 ± 0.0021
Cl	-	-	10.6 ± 0.5	266 ± 3
Co	-	-	0.95 ± 0.01	0.277 ± 0.002
Cr	-	-	0.69 ± 0.01	0.043 ± 0.004
Cs		-	0.0063 ± 0.0012	0.0056 ± 0.0006
Cu	32.7 ± 2.5	39.0 ± 2.7	<0.87	<0.09
Dy	-	-	-	-
Eu	-	-	0.0006 ± 0.0001	<0.0001
Fe	1.68 ± 0.01*	2.04 ± 0.04*	58.7 ± 2.9	3.52 ± 0.16
Ga	6.5 ± 1.2	8.8 ± 1.2	<0.54	0.05 ± 0.04
Ge	-	-	<0.51	<0.06
H	2.23*	0.21 ± 0.02*	12.6 ± 1.3*	-
Hf	-	-	0.0018 ± 0.0005	0.0016 ± 0.0002
Hg	0.070 ± 0.004	0.050 ± 0.007	0.129 ± 0.045	0.050 ± 0.002
K	1.21 ± 0.02*	1.42 ± 0.04*	25.9*± 6.6	19 ± 3
La	-	-	0.030 ± 0.006	-
Lu	-	-	-	0.00015 ± 0.00008
Mg	3.75 ± 0.04*	4.31 ± 0.11*	88.2 ± 3.4	<10
Mn	261 ± 18	343 ± 20	0.622 ± 0.006	<0.02
Mo	-	-	0.46 ± 0.14	0.15 ± 0.01
N	0.82 ± 0.14*	0.25 ± 0.04*	1.97 ± 0.20*	1.15 ± 0.02*
Na	1.37 ± 0.17*	1.70 ± 0.18*	213 ± 2	270 ± 2
Nd	-	-	-	-
Ni	20.3 ± 3.4	24.0 ± 3.7	3.55 ± 0.74	1.96 ± 0.10
Pb	20.7 ± 1.7	25.8 ± 3.4	1.6	<0.21
Rb	60.2 ± 3.0	72.6 ± 3.4	<0.72	0.17 ± 0.06
S	0.42*	0.28 ± 0.03*	0.75 ± 0.08*	0.09 ± 0.01*
Sb	-	-	0.072 ± 0.002	0.115 ± 0.001
Sc	-	-	0.0073 ± 0.0001	-
Se	1.8 ± 0.6	2.2 ± 0.6	0.54 ± 0.01	0.33 ± 0.04
Si	12.6 ± 0.1*	15.3 ± 0.3*	<86	-
Sm	-	-	0.0039 ± 0.0010	-
Sr	811 ± 40	993 ± 47	1.0 ± 0.6	0.21 ± 0.08
Ta	-	-	-	0.0066 ± 0.0041
Tb	-	-	-	-
Th	-	-	0.0046 ± 0.0009	0.0013 ± 0.0003
Ti	0.11 ± 0.01*	0.15 ± 0.02*	<1.4	<0.57
U	-	-	0.036 ± 0.011	0.038 ± 0.001
V	-	-	0.59 ± 0.04	<0.10
W	-	-	-	0.047 ± 0.005
Y	8.6 ± 1.0	13.4 ± 1.0	<1.1	<0.15
Yb	-	-	-	0.0012 ± 0.0004
Zn	50.5 ± 2.5	63.0 ± 3.0	0.47 ± 0.06	0.14 ± 0.06

*Percent

Table 139

Elemental abundances in products from run CS-72 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.40 ± 0.05*	4.09 ± 0.09*	-	-
As	25.3 ± 1.2	30.9 ± 2.2	10.5 ± 0.5	5.75 ± 0.42
Ba	-	-	-	-
C (org)	8.89 ± 0.01*	2.07 ± 0.24*	84.9 ± 8.5*	0.40*
C (inor)	5.49 ± 0.01*	4.63 ± 0.27*	-	0.97*
Ca	12.1 ± 0.1*	14.2 ± 0.3*	-	-
Cd	-	-	-	-
Ce	-	-	-	-
Cl	-	-	-	-
Co	-	-	-	<8.6
Cr	-	-	-	<5.8
Cs	-	-	-	-
Cu	30.2 ± 2.5	36.5 ± 2.7	<0.72	<0.96
Dy	-	-	-	-
Eu	-	-	-	-
Fe	1.92 ± 0.2*	2.23 ± 0.04*	23.4 ± 1.4	2.37 ± 1.60
Ga	7.2 ± 1.2	9.1 ± 1.4	<0.48	<0.60
Ge	-	-	-	<0.57
H	1.00 ± 0.08*	0.16 ± 0.04*	11.8 ± 1.2*	
Hf	-	-	-	-
Hg	0.070 ± 0.012	0.028 ± 0.007	-	0.042 ± 0.002
K	1.59 ± 0.02*	1.82 ± 0.05*	-	-
La	-	-	-	-
Lu	-	-	-	-
Mg	3.59 ± 0.07*	4.26 ± 0.07*	-	-
Mn	318 ± 20	385 ± 21	<2.2	-
Mo	-	-	-	-
N	0.30 ± 0.01*	0.27 ± 0.09*	2.13 ± 0.21*	1.69 ± 0.01*
Na	1.47 ± 0.18*	1.84 ± 0.18*	-	-
Nd	-	-	-	-
Ni	16.5 ± 3.5	19.3 ± 3.7	7.96 ± 0.70	2.00 ± 0.78
Pb	17.6 ± 1.7	23.4 ± 2.0	<1.6	<1.7
Rb	60.0 ± 3.0	69.8 ± 3.3	<0.69	0.80 ± 0.60
S	0.40 ± 0.01*	0.32 ± 0.06*	0.62 ± 0.06*	0.07 ± 0.02*
Sb	-	-	-	-
Sc	-	-	-	-
Se	1.3 ± 0.6	1.8 ± 0.6	0.65 ± 0.28	0.59 ± 0.30
Si	13.4 ± 0.1*	15.8 ± 0.4*	-	-
Sm	-	-	-	-
Sr	822 ± 41	974 ± 47	<1.2	0.91 ± 0.64
Ta	-	-	-	-
Tb	-	-	-	-
Th	-	-	-	<1.5
Ti	0.14 ± 0.01*	0.16 ± 0.01*	<8.6	<18
U	-	-	-	<2.5
V	-	-	-	<10
W	-	-	-	-
Y	10.0 ± 1.0	14.7 ± 1.0	<1.0	1.1
Yb	-	-	-	-
Zn	57.4 ± 2.8	70.0 ± 3.8	0.59 ± 0.40	<0.72

*Percent

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Table 140

Elemental abundances in products from run CS-73 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.69 ± 0.06*	4.38 ± 0.08*	-	-
As	15.1 ± 0.8	17.8 ± 1.0	3.43 ± 0.36	2.53 ± 0.36
Ba	-	-	-	-
C (org)	13.0 ± 0.2*	6.59 ± 0.66*	81.0 ± 8.1*	0.63*
C (inor)	4.27 ± 0.03*	4.73 ± 0.17*	-	0.36*
Ca	12.6 ± 0.1*	14.8 ± 0.9*	-	-
Cd	-	-	-	-
Ce	-	-	-	-
Cl	-	-	-	-
Co	-	-	-	<9.5
Cr	-	-	-	<6.7
Cs	-	-	-	-
Cu	58.2 ± 2.9	71.2 ± 3.6	<1.5	<0.99
Dy	-	-	-	-
Eu	-	-	-	-
Fe	1.97 ± 0.01*	2.42 ± 0.34*	22.6 ± 3.4	1.87 ± 1.74
Ga	7.7 ± 1.2	9.2 ± 1.3	<0.9	<0.60
Ge	-	-	-	<0.54
H	1.84 ± 0.01*	0.33 ± 0.09*	10.5 ± 1.1*	-
Hf	-	-	-	-
Hg	0.129 ± 0.016	0.028 ± 0.004	<0.105	0.250 ± 0.025
K	0.767 ± 0.015*	0.923 ± 0.169*	-	-
La	-	-	-	-
Lu	-	-	-	
Mg	1.99 ± 0.06*	2.84 ± 0.42*	-	-
Mn	111 ± 17	118 ± 18	<5.1	-
Mo	-	-	-	-
N	0.56 ± 0.01*	0.30 ± 0.06*	1.56 ± 0.16*	1.26 ± 0.06*
Na	-	-	-	-
Nd	-	-	-	-
Ni	128 ± 6	151 ± 7	8.12 ± 0.88	4.28 ± 0.86
Pb	3.0 ± 1.6	7.5 ± 2.2	<2.7	<1.7
Rb	40.2 ± 2.0	46.6 ± 2.2	<1.2	0.72 ± 0.48
S	1.86 ± 0.01*	0.76 ± 0.06*	6.56 ± 0.66*	0.78 ± 0.01*
Sb	-	-	-	-
Sc	-	-	-	-
Se	17.8 ± 0.8	20.0 ± 1.5	12.4 ± 0.6	7.74 ± 0.40
Si	11.9 ± 0.1*	13.7 ± 0.4*	-	-
Sm	-	-	-	-
Sr	404 ± 20	471 ± 24	<1.2	<0.93
Ta	-	-	-	-
Tb	-	-	-	-
Th	-	-	-	<1.4
Ti	0.21 ± 0.01*	0.23 ± 0.02*	<25.5	<22
U	-	-	-	<2.5
V	-	-	-	<12
W	-	-	-	-
Y	31.7 ± 1.5	39.0 ± 2.2	<1.5	<1.1
Yb	-	-	-	-
Zn	336 ± 16	408 ± 19	0.91 ± 0.50	<0.75

*Percent

Table 141

Elemental abundances in products from run CS-74.

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	3.34 ± 0.05*	5.19 ± 0.26*	-	-
As	24.2 ± 1.2	38.5 ± 1.6	12.1 ± 0.6	3.97 ± 0.38
Ba	-	-	-	-
C (org)	9.28 ± 0.05*	0.33 ± 0.11*	84.6 ± 8.5*	0.32*
C (inor)	5.60 ± 0.01*	0.60 ± 0.29*	-	1.41*
Ca	12.0 ± 0.1*	15.7 ± 0.7*	-	-
Cd	-	-	-	-
Ce	-	-	-	-
Cl	-	-	-	-
Co	-	-	-	<6.9
Cr	-	-	-	<6.5
Cs	-	-	-	-
Cu	32.9 ± 2.5	46.8 ± 6.2	<0.72	<0.96
Dy	-	-	-	-
Eu	-	-	-	-
Fe	1.84 ± 0.01*	3.04 ± 0.13*	29.2 ± 1.6	4.26 ± 1.76
Ga	8.2 ± 1.2	12.2 ± 1.3	<0.6	<0.47
Ge	<1.5	<1.8	<0.6	<0.57
H	1.33 ± 0.03*	trace	11.8 ± 1.7	-
Hf	-	-	-	-
Hg	0.079 ± 0.001	0.017 ± 0.001	-	0.023 ± 0.004
K	1.53 ± 0.02*	2.46 ± 0.40*		
La	-	-	-	-
Lu	-	-	-	-
Mg	3.54 ± 0.07*	5.30 ± 0.08*	-	-
Mn	-	-	-	-
Mo	-	-	-	-
N	0.41 ± 0.02*	0.13 ± 0.01*	2.22 ± 0.22*	2.82 ± 0.03*
Na	1.57 ± 0.18*	1.98 ± 0.18*	-	-
Nd	-	-	-	-
Ni	14.3 ± 3.4	27.5 ± 3.7	7.4 ± 0.6	2.06 ± 0.82
Pb	16.7 ± 1.7	26.5 ± 2.0	<1.5	<1.7
Rb	59.0 ± 2.9	89.4 ± 6.2	<0.69	0.60 ± 0.46
S	0.57 ± 0.02*	0.51 ± 0.04*	0.57 ± 0.06*	0.05 ± 0.01*
Sb	-	-	-	-
Sc	-	-	-	-
Se	1.8 ± 0.6	2.9 ± 0.6	0.83 ± 0.28	1.29 ± 0.32
Si	13.1 ± 0.1*	19.4 ± 0.9*	-	-
Sm	-	-	-	-
Sr	816 ± 40	1080 ± 78	<0.9	0.73 ± 0.62
Ta	-	-	-	-
Tb	-	-	-	-
Th	-	-	-	<1.4
Ti	0.13 ± 0.01*	0.20 ± 0.03*	9.0	<21
U	-	-	-	<2.5
V	-	-	-	<12
W	-	-	-	-
Y	10.6 ± 1.0	20.8 ± 2.2	<0.9	<1.1
Yb	-	-	-	-
Zn	55.9 ± 2.7	85.2 ± 5.0	0.61 ± 0.40	<0.72

*Percent

Table 142

Elemental abundances in products from run S-7 (ppm).

	Raw oil shale	Spent oil shale
Al	4.04 ± 0.05[*]	5.07 ± 0.19[*]
As	37.3 ± 1.6	53.4 ± 2.6
Ba	498 ± 22	632 ± 19
C (org)	10.8 ± 2.8[*,a]	0.08[*,a]
C (inor)	4.73 ± 0.5[*,a]	3.02[*,a]
Ca	8.82 ± 0.08[*]	11.5 ± 0.4[*]
Cd	0.72 ± 0.07	0.87 ± 0.09
Ce	43.6 ± 0.4	56 ± 3
Cl	.	-
Co	9.18 ± 0.12	11.8 ± 0.2
Cr	37.3 ± 0.5	46.4 ± 0.8
Cs	4.69 ± 0.33	6.44 ± 0.17
Cu	40.2 ± 3.0	52.1 ± 4.8
Dy	2.48 ± 0.05	3.08 ± 0.08
Eu	0.634 ± 0.007	0.804 ± 0.012
Fe	2.24 ± 0.07[*]	2.63 ± 0.04[*]
Ga	9.8 ± 1.8	13.0 ± 2.2
Ge	<2.4	2.2 ± 1.8
H	1.67 ± 0.08[*,a]	0.19[*,a]
Hf	1.71 ± 0.05	2.42 ± 0.02
Hg	0.084 ± 0.006	0.014 ± 0.001
K	1.70 ± 0.05[*]	2.16 ± 0.10[*]
La	20.8 ± 0.4	27.9 ± 0.7
Lu	0.19 ± 0.01	0.21 ± 0.02
Mg	3.43 ± 0.08[*]	4.50 ± 0.10[*]
Mn	342 ± 7	414 ± 8
Mo	20.8 ± 1.4	33.2 ± 3.3
N	0.51 ± 0.05[*,a]	0.37[*,a]
Na	1.63 ± 0.10[*]	2.25 ± 0.06[*]
Nd	19 ± 1	24 ± 2
Ni	20.4 ± 4.0	36.1 ± 6.4
Pb	23.6 ± 1.9	40.3 ± 3.2
Rb	74.2 ± 2.1	94.0 ± 3.8
S	0.66 ± 0.07[*,a]	0.30[*,a]
Sb	2.23 ± 0.26	2.82 ± 0.19
Sc	6.47 ± 0.02	7.88 ± 0.21
Se	2.1 ± 0.7	3.5 ± 1.2
Si	15.4 ± 0.8[*]	19.3 ± 0.5[*]
Sm	3.08 ± 0.06	3.98 ± 0.21
Sr	682 ± 19	876 ± 35
Ta	0.47 ± 0.03	0.61 ± 0.02
Tb	0.40 ± 0.06	0.47 ± 0.12
Th	6.70 ± 0.03	8.71 ± 0.06
Ti	0.15 ± 0.01[*]	0.19 ± 0.03[*]
U	4.24 ± 0.20	5.84 ± 0.05[*]
V	104 ± 10	126 ± 15
W	1.4 ± 0.2	1.8 ± 0.5
Y	13.3 ± 1.3	17.7 ± 2.0
Yb	1.36 ± 0.02	1.82 ± 0.3
Zn	67.2 ± 2.6	111 ± 4

[*] Percent

[a] Libicki (1980)

Table 143

Elemental abundances in products from run S-9 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	4.04 ± 0.05[*]	4.69 ± 0.06[*]	0.5 ± 0.1	15.9 ± 0.5
As	37.3 ± 1.4	47.5 ± 2.4	11 ± 4	0.47 ± 0.08
Ba	498 ± 22	597 ± 20	-	-
C (org)	10.8 ± 2.8[*][a]	2.70 ± 0.27[*]	84.41[*][a]	0.31 ± 0.10[*]
C (inor)	4.73 ± 0.5[*][a]	5.45 ± 0.35[*]	-	0.33 ± 0.08[*]
Ca	8.82 ± 0.08[*]	10.5 ± 0.1	-	-
Cd	0.72 ± 0.07	0.87 ± 0.09	<0.010	<0.002
Ce	43.6 ± 0.4	48.6 ± 0.3	-	-
Cl	-	-	90 ± 21	<5
Co	9.18 ± 0.12	10.5 ± 0.1	1.21 ± 0.01	<0.03
Cr	37.3 ± 0.5	38.9 ± 0.5	0.06 ± 0.01	<0.4
Cs	11.69 ± 0.33	5.55 ± 0.11	-	-
Cu	40.2 ± 3.0	53.5 ± 4.6	3.3 ± 1.1	3.3 ± 0.3
Dy	2.48 ± 0.05	2.72 ± 0.06	-	-
Eu	0.634 ± 0.007	0.708 ± 0.007	-	-
Fe	2.24 ± 0.07[*]	2.33 ± 0.07[*]	39 ± 2	1.38 ± 0.06
Ga	9.8 ± 1.8	11.7 ± 2.2	<0.08	-
Ge	<2.4	8.6 ± 1.8	<0.48	-
H	1.67 ± 0.08[*][a]	0.28[*]	11.96[*][a]	-
Hf	1.71 ± 0.05	-	-	-
Hg	0.084 ± 0.006	0.036 ± 0.001	0.064 ± 0.020	0.079 ± 0.005
K	1.70 ± 0.05[*]	1.92 ± 0.04[*]	-	-
La	20.8 ± 0.4	23.8 ± 0.60	0.003 ± 0.001	-
Lu	0.189 ± 0.011	0.14 ± 0.01	-	-
Mg	3.43 ± 0.8[*]	4.30 ± 0.10[*]	1.5 ± 0.5	<40
Mn	342 ± 7	368 ± 7	0.13 ± 0.01	0.22 ± 0.03
Mo	20.8 ± 1.4	25.0 ± 1.9	0.26 ± 0.05	-
N	0.31 ± 0.05[*][a]	<0.01[*]	1.94[*][a]	-
Na	1.63 ± 0.10[*]	2.07 ± 0.01[*]	7.8 ± 0.1	48 ± 4
Nd	19 ± 1	17 ± 1	-	-
Ni	20.4 ± 4.0	29.9 ± 6.2	4.2 ± 0.2	0.24 ± 0.03
Pb	23.6 ± 1.9	32.8 ± 3.0	1.5 ± 0.6	-
Rb	74.2 ± 2.1	87.2 ± 3.5	<0.6	0.06 ± 0.01
S	0.66 ± 0.07[*][a]	0.30[*]	0.72[*][a]	-
Sb	2.23 ± 0.26	2.33 ± 0.14	0.023 ± 0.008	-
Sc	6.47 ± 0.02	6.71 ± 0.02	0.0007 ± 0.0001	-
Se	2.1 ± 0.7	3.4 ± 1.0	0.9 ± 0.1	0.30 ± 0.02
Si	15.4 ± 0.8[*]	17.9 ± 0.1[*]	-	-
Sm	3.08 ± 0.06	3.42 ± 0.10	0.0004 ± 0.0002	-
Sr	682 ± 19	794 ± 31	<5.5	-
Ta	0.47 ± 0.03	0.669 ± 0.003	-	-
Tb	0.40 ± 0.06	0.45 ± 0.08	-	-
Th	6.70 ± 0.03	7.67 ± 0.04	0.006 ± 0.001	<0.01
Ti	0.15 ± 0.01[*]	0.18 ± 0.03[*]	<0.27	2.4 ± 0.9
U	4.24 ± 0.20	6.68 ± 0.04	0.007 ± 0.002	-
V	104 ± 10	107 ± 13	0.30 ± 0.04	0.09 ± 0.01
W	1.4 ± 0.2	-	-	-
Y	23.3 ± 1.3	16.5 ± 2.0	<1.0	-
Yb	1.36 ± 0.02	1.39 ± 0.02	-	-
Zn	67.2 ± 2.6	89.0 ± 4.0	3.0 ± 0.7	0.10 ± 0.02

[*] Percent

[a] Tripp (1979b)

Table 144

…l abundances in products from run S-10 (ppm).

		Spent oil shale	Shale oil	Retort water
Al		3.84 ± 0.10*	-	16.4 ± 0.5
As		76.0 ± 3.0	18.7 ± 3.1	1.48 ± 0.08
Ba		715 ± 20	-	-
C (org		0.034*[a]	85.3 ± 8.5*[a]	0.36 ± 0.09*
C (inor		0.40 ± 0.03*[a]	-	1.76 ± 0.11*
Ca		12.0 ± 0.3*	-	6 ± 1
Cd		0.84 ± 0.08	0.030 ± 0.003	<0.002
Ce		66 ± 4	-	-
Cl		-	850 ± 10	<6
Co		13.7 ± 0.2	1.09 ± 0.13	<0.81
Cr		51.4 ± 0.9	0.07 ± 0.01	<0.27
Cs		6.41 ± 0.15	-	-
Cu		56.4 ± 5.2	11.5 ± 1.2	0.87 ± 0.08
Dy		3.43 ± 0.09	-	-
Eu	[illegible]	0.965 ± 0.012	-	-
Fe		3.06 ± 0.06*	49.3 ± 5.5	2.34 ± 0.16
Ga		13.9 ± 2.4	<0.1	<0.06
Ge		<3.0	<0.48	<0.06
H		0.020 ± 0.001*[a]	11.36 ± 1.14*[a]	-
Hf		-	-	<0.12
Hg	0.	<0.010	0.149 ± 0.038	<0.00050
K		2.41 ± 0.04*	-	6 ± 3
[illegible]		33.0 ± 0.9	-	-
[illegible]	0.	0.23 ± 0.02	-	-
[illegible]		4.69 ± 0.09*	-	-
[illegible]		[illegible]67 ± 9	0.22 ± 0.01	0.39 ± 0.03
[illegible]		31.0 ± 2.8	-	-
N		0.15 ± 0.02*[a]	2.07 ± 0.21*[a]	-
Na		2.59 ± 0.02*[a]	16 ± 4	45 ± 4
Nd		27 ± 2	-	-
Ni		33.6 ± 6.8	4.1 ± 0.7	0.48 ± 0.08
Pb		34.7 ± 3.4	2.4 ± 1.0	<0.24
Rb		104 ± 4	-	<0.09
S		0.30 ± 0.03*[a]	0.76 ± 0.08*[a]	-
Sb		3.01 ± 0.18	0.021 ± 0.003	-
Sc		8.79 ± 0.24	-	-
Se		3.0 ± 1.2	0.67 ± 0.02	0.77 ± 0.04
Si	15.	22.1 ± 0.1*	-	-
Sm	3.08	4.52 ± 0.23	-	-
Sr	[illegible]	962 ± 38	<0.13	<0.12
Ta		0.73 ± 0.03	-	-
Tb		0.56 ± 0.13	-	-
Th		9.93 ± 0.06	0.003 ± 0.001	<0.18
Ti		0.24 ± 0.01*	<9.5	<0.57
U	4.24	6.49 ± 0.05	-	<0.30
V	104	129 ± 26	0.41 ± 0.01	0.08 ± 0.01
W	1.4	2.0 ± 0.4	-	-
Y	.3	19.1 ± 2.2	<0.13	<0.15
Yb	36	1.98 ± 0.03	-	-
[illegible]	.2	97.6 ± 4.6	1.9 ± 0.6	0.24 ± 0.06

…m Ac… et al. (1978a).

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Table 145

Elemental abundances in products from run S-11.

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	4.04 ± 0.05*	5.64 ± 0.06*	0.54 ± 0.08	12.5 ± 0.5
As	37.3 ± 1.4	55.6 ± 2.6	14 ± 3	2.57 ± 0.13
Ba	498 ± 22	719 ± 20	<0.5	-
C (org)	10.8 ± 2.8*[a]	0.007 ± 0.002*[a]	82.4 ± 8.2*[a]	0.21 ± 0.04*
C (inor)	4.73 ± 0.05*[a]	0.21 ± 0.02*[a]	-	1.20 ± 0.02
Ca	8.82 ± 0.08*	12.3 ± 0.1*	-	21 ± 4
Cd	0.72 ± 0.07	0.77 ± 0.08	0.025 ± 0.003	0.005 ± 0.0005
Ce	43.6 ± 0.4	63 ± 4	-	-
Cl	-	-	3.5 ± 0.1	11 ± 2
Co	9.18 ± 0.12	12.6 ± 0.2	0.35 ± 0.08	<0.03
Cr	37.3 ± 0.5	59.7 ± 0.9	0.14 ± 0.09	0.39 ± 0.22
Cs	4.69 ± 0.33	6.96 ± 0.16	-	-
Cu	40.2 ± 3.0	55.2 ± 5.2	2.5 ± 0.2	133 ± 6
Dy	2.48 ± 0.05	3.65 ± 0.09	-	-
Eu	0.634 ± 0.007	0.931 ± 0.011	<0.001	-
Fe	2.24 ± 0.07*	3.08 ± 0.14*	40 ± 9	27.2 ± 2.2
Ga	9.8 ± 1.8	12.7 ± 2.4	<0.1	<0.09
Ge	<2.4	2.1 ± 2.0	<0.45	<0.06
H	1.67 ± 0.08*[a]	0.03 ± 0.001*[a]	10.93 ± 1.09*[a]	-
Hf	1.71 ± 0.05	2.84 ± 0.23	-	-
Hg	0.084 ± 0.006	0.0011 ± 0.0004	0.220 ± 0.042	0.085 ± 0.011
K	1.70 ± 0.05*	2.50 ± 0.04*	-	26 ± 3
La	20.8 ± 0.4	31.9 ± 0.6	<0.003	-
Lu	0.189 ± 0.011	0.32 ± 0.02	-	-
Mg	3.43 ± 0.08*	4.72 ± 0.09*	-	<39
Mn	342 ± 7	482 ± 10	0.039 ± 0.001	0.19 ± 0.03
Mo	20.8 ± 1.4	27.7 ± 2.3	0.86 ± 0.26	-
N	0.51 ± 0.005*[a]	0.20 ± 0.002*[a]	1.71 ± 0.17*[a]	-
Na	1.63 ± 0.10*	2.45 ± 0.02*	0.77 ± 0.01	52 ± 3
Nd	19 ± 1	25 ± 2	-	-
Ni	20.4 ± 4.0	30.6 ± 7.0	2.9 ± 0.4	1.57 ± 0.10
Pb	23.6 ± 1.9	37.2 ± 3.4	1.5 ± 0.6	1.15 ± 0.16
Rb	74.2 ± 2.1	105 ± 4	<0.05	0.07 ± 0.06
S	0.66 ± 0.07*[a]	0.30 ± 0.03*[a]	0.86 ± 0.09*[a]	-
Sb	2.23 ± 0.26	3.07 ± 0.19	0.03 ± 0.01	<0.07
Sc	6.47 ± 0.02	9.28 ± 0.25	0.0004 ± 0.0001	-
Se	2.1 ± 0.7	2.2 ± 0.6	2.9 ± 0.3	1.09 ± 0.06
Si	15.4 ± 0.8*	21.7 ± 0.1*	-	-
Sm	3.08 ± 0.06	4.49 ± 0.23	0.019 ± 0.004	-
Sr	682 ± 19	944 ± 37	<0.87	<0.12
Ta	0.47 ± 0.03	0.69 ± 0.03	-	-
Tb	0.40 ± 0.06	0.60 ± 0.14	-	-
Th	6.70 ± 0.03	9.85 ± 0.06	<0.0006	<0.01
Ti	0.15 ± 0.01*	0.23 ± 0.02*	<0.31	0.86 ± 0.42
U	4.24 ± 0.20	6.33 ± 0.05	-	<0.30
V	104 ± 10	141 ± 18	0.29 ± 0.01	0.08 ± 0.01
W	1.4 ± 0.2	1.8 ± 0.4	-	-
Y	13.3 ± 1.3	21.4 ± 2.2	<0.14	<0.15
Yb	1.36 ± 0.02	2.06 ± 0.03	-	-
Zn	67.2 ± 2.6	116 ± 4	5.4 ± 1.7	13.3 ± 0.6

*Percent.

[a] Data from [illegible] et al. ([illegible]).

Table 146

Elemental abundances in products from run S-12 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	4.04 ± 0.05*	5.62 ± 0.08*	1.2 ± 0.9	-
As	37.3 ± 1.4	56.4 ± 2.3	5.12 ± 0.36	2.61 ± 0.38
Ba	498 ± 22	689 ± 17	-	-
C (org)	11.1 ± 2.9*[a]	0.030 ± 0.009*[a]	60.0 ± 8.0*[a]	-
C (inor)	4.63 ± .5*[a]	0.69 ± 0.07*[a]	-	-
Ca	8.82 ± 0.08*	13.3 ± 0.1*	-	-
Cd	0.72 ± 0.07	-	-	0.034 ± 0.009
Ce	43.6 ± 0.4	60.7 ± 0.8	-	0.027 ± 0.004
Cl	-	-	343 ± 3	368 ± 3
Co	9.18 ± 0.12	13.2 ± 0.2	0.481 ± 0.002	0.0347 ± 0.0004
Cr	37.3 ± 0.5	122 ± 1	0.361 ± 0.004	0.049 ± 0.004
Cs	11.69 ± 0.33	6.42 ± 0.17	-	0.0074 ± 0.0005
Cu	40.2 ± 3.0	67.0 ± 3.4	4.1 ± 0.2	139 ± 6
Dy	2.48 ± 0.05	3.46 ± 0.10	-	-
Eu	0.634 ± 0.007	0.909 ± 0.013	0.00007 ± 0.00005	0.0002 ± 0.0001
Fe	2.24 ± 0.07*	3.09 ± 0.04*	80.9 ± 4.0	16.2 ± 2.0
Ga	9.8 ± 1.8	13.3 ± 1.6	0.008 ± 0.003	0.013 ± 0.007
Ge	<2.4	<1.8	0.45	<0.6
H	1.65 ± .08*[a]	0.06 ± 0.003*[a]	11.19 ± 1.12*[a]	-
Hf	1.71 ± 0.05	2.67 ± 0.06	-	-
Hg	0.084 ± 0.006	0.0039 ± 0.0007	-	0.017 ± 0.002
K	1.70 ± 0.05*	2.44 ± 0.03*	-	6.6 ± 1.1
La	20.8 ± 0.4	30.7 ± 0.7	-	0.0080 ± 0.0005
Lu	0.189 ± 0.011	0.26 ± 0.02	-	-
Mg	3.43 ± 0.08*	5.12 ± 0.10*	-	4.3 ± 3.1
Mn	342 ± 7	498 ± 10	0.095 ± 0.003	0.175 ± 0.003
Mo	20.8 ± 1.4	29.2 ± 2.4	0.14 ± 0.01	-
N	0.56 ± .05*[a]	0.02 ± 0.002*[a]	1.42 ± 0.14*[a]	-
Na	1.63 ± 0.10*	2.37 ± 0.06*	0.015 ± 0.002	18.6 ± 0.3
Nd	19 ± 1	25 ± 2	-	-
Ni	20.4 ± 4.0	40.9 ± 4.4	2.34 ± 0.60	1.05 ± 0.07
Pb	23.6 ± 1.9	64.9 ± 2.6	<1.6	<1.7
Rb	74.2 ± 2.1	106 ± 4	<0.72	0.032 ± 0.008
S	0.33 ± .04*[a]	0.53 ± 0.05*[a]	0.93 ± 0.09*[a]	-
Sb	2.23 ± 0.26	3.10 ± 0.20	0.0029 ± 0.0003	1.102 ± 0.001
Sc	6.47 ± 0.02	8.84 ± 0.24	-	-
Se	2.1 ± 0.7	2.5 ± 0.8	1.23 ± 0.01	1.42 ± 0.01
Si	15.4 ± 0.8*	21.1 ± 0.1*	102 ± 72	-
Sm	3.08 ± 0.06	4.34 ± 0.20	-	-
Sr	682 ± 19	962 ± 38	<0.87	<1.0
Ta	0.47 ± 0.03	1.05 ± 0.01	-	-
Tb	0.40 ± 0.06	0.57 ± 0.03	-	-
Th	6.90 ± 0.03	9.36 ± 0.07	<1.3	<1.5
Ti	0.15 ± 0.01*	0.23 ± 0.03*	2.2 ± 1.5	2.7 ± 1.9
U	4.24 ± 0.20	6.88 ± 0.06	<2.3	0.0116 ± 0.0003
V	106 ± 10	128 ± 19	0.23 ± 0.02	0.023 ± 0.017
W	1.4 ± 0.2	2.7 ± 0.9	-	0.019 ± 0.001
Y	13.3 ± 1.3	21.2 ± 1.2	<1.0	0.8 ± 0.8
Yb	1.36 ± 0.02	1.91 ± 0.04	-	-
Zn	67.2 ± 2.6	179 ± 7	6.00 ± 0.06	13.2 ± 0.8

*Percent

[a] Data from Ackerman et al. (1978b).

Table 147

Elemental abundances in products from run S-13 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	4.04 ± 0.05%	5.66 ± 0.06%	0.9 ± 0.6	-
As	37.3 ± 1.4	56.9 ± 2.2	22.2 ± 1.0	0.357 ± 0.002
Ba	498 ± 22	-	-	-
C (org)	10.8 ± 2.9%[a]	0.179%[a]	81.97%[a]	0.24 ± 0.01%
C (inor)	4.71 ± 0.5%[a]	0.382%[a]	-	0.404 ± 0.001%
Ca	8.82 ± 0.08%	13.2 ± 0.1%	-	-
Cd	0.72 ± 0.07	-	-	-
Ce	43.6 ± 0.4	-	0.009 ± 0.003	-
Cl	-	-	332 ± 3	352 ± 3
Co	9.18 ± 0.12	<26.4	1.42 ± 0.01	0.184 ± 0.001
Cr	37.3 ± 0.5	-	0.406 ± 0.006	0.070 ± 0.003
Cs	4.69 ± 0.33	-	-	-
Cu	40.2 ± 3.0	54.5 ± 3.5	16.6 ± 0.8	<0.9
Dy	2.48 ± 0.05	-	-	-
Eu	0.634 ± 0.007	-	0.00013±0.00009	0.00008±0.00006
Fe	2.24 ± 0.07%	3.04 ± 0.13%	104 ± 5	1.71 ± 0.16
Ga	9.8 ± 1.8	13.7 ± 1.6	0.028 ± 0.007	<0.6
Ge	<2.6	-	<0.51	<0.5
H	1.67 ± 0.08%[a]	0.03%[a]	11.37%[a]	-
Hf	1.71 ± 0.05	-	-	-
Hg	0.084 ± 0.006	<0.010	0.156 ± 0.035	<0.016
K	1.70 ± 0.05%	2.51 ± 0.03%	-	5.8 ± 1.1
La	20.8 ± 0.4	-	0.0017 ± 0.0004	0.00094±0.00016
Lu	0.189 ± 0.011	-	-	-
Mg	3.43 ± 0.08%	5.12 ± 0.09%	-	4.1 ± 3.0
Mn	342 ± 7	-	0.250 ± 0.004	0.0022 ± 0.0029
Mo	20.8 ± 1.4	-	2.16 ± 0.03	-
N	0.51 ± 0.05%[a]	-	1.97%[a]	-
Na	1.63 ± 0.10%	2.39 ± 0.26%	0.224 ± 0.006	26.0 ± 0.3
Nd	19 ± 1	-	-	-
Ni	20.4 ± 4.0	38.8 ± 4.8	4.79 ± 0.76	0.27 ± 0.05
Pb	23.6 ± 1.9	41.9 ± 2.4	<2.2	<1.7
Rb	74.2 ± 2.1	105 ± 4	<0.72	<0.7
S	0.66 ± 0.07%[a]	0.47%[a]	0.81%[a]	-
Sb	2.23 ± 0.26	-	0.151±0.0005	0.0033±0.0001
Sc	6.47 ± 0.02	-	0.00021±0.00008	-
Se	2.1 ± 0.7	2.1 ± 0.8	2.18 ± 0.01	0.487 ± 0.004
Si	15.4 ± 0.8%	21.1 ± 0.1%	52 ± 58	-
Sm	3.08 ± 0.06	-	-	0.00006±0.00004
Sr	682 ± 19	957 ± 38	<1.2	<1.0
Ta	0.47 ± 0.03	-	-	0.0056 ± 0.0011
Tb	0.40 ± 0.06	-	-	-
Th	6.70 ± 0.03	-	0.0020 ± 0.0007	<1.4
Ti	0.15 ± 0.01%	0.23 ± 0.01%	1.9 ± 1.4	2.2 ± 1.6
U	4.24 ± 0.20	-	<2.4	0.0155 ± 0.0002
V	104 ± 10	-	0.51 ± 0.03	0.023 ± 0.017
W	1.4 ± 0.2	-	-	0.011 ± 0.001
Y	13.3 ± 1.3	21.9 ± 1.3	<1.0	<1.1
Yb	1.36 ± 0.02	-	-	0.0014 ± 0.0003
Zn	67.2 ± 2.6	118 ± 4	5.10 ± 0.07	<0.7

[a] Data from Ackerman et al. (1979a).

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Table 148

[illegible] Elemental abundances in products from run S-14 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	[illegible] ± 0.05[*]	5.72 ± 0.08[*]	<0.2	-
As	[illegible] ± 1.4	62.4 ± 2.4	19.8 ± 0.9	0.427 ± 0.003
Ba	[illegible] ± 22	-	-	-
C (org)	[illegible] ± 2.9[*,a]	0.12[*,a]	82.98[*,a]	-
C (inor)	[illegible].67[*,a]	0.25[*,a]	-	-
Ca	8.42 ± 0.08[*]	13.4 ± 0.1[*]	-	-
Cd	[illegible] ± 0.07	-	-	0.025 ± 0.007
Ce	[illegible] ± 0.4	-	-	-
Cl	-	-	30.2 ± 0.6	353 ± [illegible]
Co	[illegible] ± 0.12	-	1.79 ± 0.01	0.030 ± 0.001
Cr	[illegible] ± 0.5	-	0.519 ± 0.008	0.306 ± 0.006
Cs	[illegible] ± 0.33	-	-	-
Cu	[illegible] ± 3.0	80.0 ± 3.7	15.6 ± 0.7	<2.1
Dy	[illegible] ± 0.05	-	-	-
Eu	[illegible] ± 0.007	-	<0.0002	<0.00008
Fe	[illegible] ± 0.07[*]	3.20 ± 0.08[*]	57.0 ± 2.8	28.1 ± 0.4
Ga	9.8 ± 1.8	15.5 ± 1.7	0.054 ± 0.010	<1.3
Ge	<2.4	<2.1	<0.51	<1.2
H	[illegible] ± 0.08[*,a]	0.043[*,a]	11.22[*,a]	-
Hf	[illegible] ± 0.05	-	-	-
Hg	[illegible] ± 0.006	0.001 ± 0.0004	0.368 ± 0.046	0.044 ± 0.004
K	[illegible] ± 0.05[*]	2.48 ± 0.03[*]	-	-
La	[illegible] ± 0.4	-	-	0.00027 ± 0.00013
Lu	[illegible] ± 0.011	-	-	-
Mg	[illegible] ± 0.08[*]	5.33 ± 0.10[*]	-	<9.2
Mn	[illegible]	-	0.236 ± 0.002	1.01 ± 0.01
Mo	[illegible] ± 1.4	-	1.23 ± 0.04	-
N	[illegible] ± 0.05[*,a]	-	1.83[*,a]	-
Na	[illegible] ± 0.10[*]	2.51 ± 0.26[*]	0.083 ± 0.009	3.06 ± 0.11
Nd	[illegible] ± 1	-	-	-
Ni	[illegible] ± 4.0	49.5 ± 5.0	6.84 ± 0.68	<2.5
Pb	[illegible] ± 1.9	74.7 ± 2.9	4.5 ± 1.1	<3.6
Rb	[illegible] ± 2.1	104 ± 4	<0.69	<1.6
S	[illegible] ± 0.07[*,a]	0.44[*,a]	0.71[*,a]	-
Sb	[illegible] ± 0.26	-	0.044 ± 0.001	0.0049 ± 0.0001
Sc	[illegible] ± 0.02	-	-	-
Se	2.1 ± 0.7	2.1 ± 0.8	2.71 ± 0.02	0.465 ± 0.007
Si	[illegible] ± 0.8[*]	21.8 ± 0.1[*]	<89	-
Sm	1.08 ± 0.06	-	-	-
Sr	[illegible] ± 19	965 ± 38	<1.2	<2.0
Ta	[illegible] ± 0.03	-	-	-
Tb	[illegible] ± 0.06	-	-	-
Th	[illegible] ± 0.03	-	<1.4	<3.0
Ti	[illegible] ± 0.01[*]	0.26 ± 0.01[*]	<0.6	<2.4
U	[illegible] ± 0.20	-	0.011 ± 0.002	0.0052 ± 0.00002
V	104 ± 10	-	0.94 ± 0.03	<0.03
W	[illegible] ± 0.2	-	-	0.0057 ± 0.0010
Y	[illegible] ± 1.3	22.2 ± 1.3	<1.0	<2.3
Yb	[illegible] ± 0.02	-	-	0.00094 ± 0.00070
Zn	[illegible] ± 2.6	165 ± 6	3.42 ± 0.09	0.31 ± 0.02

[*] Percent

[a] Data from Ackerman et al. (1979b).

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Elemental abundances in products from run S-15 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	4.04 ± 0.05*	5.73 ± 0.08*	1.6 ± 0.6	-
As	37.3 ± 1.4	49.4 ± 2.5	18.0 ± 0.9	0.284 ± 0.002
Ba	498 ± 22	-	<0.6	-
C (org)	11.4 ± 2.9*[a]	0.18*[a]	82.16*[b]	0.28 ± 0.01*
C (inor)	4.21*[a]	0.23*[a]	-	0.536 ± 0.004*
Ca	8.82 ± 0.08*	12.5 ± 0.1*	-	-
Cd	0.72 ± 0.07	-	-	-
Ce	43.6 ± 0.4	-	0.038 ± 0.004	-
Cl	-	-	43.8 ± 0.7	370 ± 8
Co	9.18 ± 0.12	-	1.87 ± 0.01	0.031 ± 0.001
Cr	37.3 ± 0.5	-	2.56 ± 0.02	2.92 ± 0.02
Cs	4.69 ± 0.33	-	-	-
Cu	40.2 ± 3.0	83.1 ± 4.0	24.8 ± 1.2	2.07 ± 0.69
Dy	2.48 ± 0.05	-	0.006 ± 0.002	-
Eu	0.634 ± 0.007	-	0.0007 ± 0.0002	<0.00008
Fe	2.24 ± 0.07*	3.32 ± 0.24*	80.2 ± 4.0	3.39 ± 0.20
Ga	9.8 ± 1.8	13.7 ± 1.7	0.10 ± 0.03	<0.6
Ge	<2.4	<2.1	<0.48	<0.6
H	1.63 ± 0.08*[b]	0.04*[b]	11.27*[b]	-
Hf	1.71 ± 0.05	-	-	-
Hg	0.084 ± 0.006	0.001 ± 0.000[illegible]	0.369 ± 0.048	<0.017
K	1.70 ± 0.05*	2.29 ± 0.03*	-	-
La	20.8 ± 0.4	-	0.0156 ± 0.0025	0.00025±0.00014
Lu	0.189 ± 0.011	-	-	-
Mg	3.43 ± 0.08*	5.00 ± 0.09*	-	<3.1
Mn	342	-	1.65 ± 0.01	0.091 ± 0.003
Mo	20.8 ± 1.4	-	0.99 ± 0.05	0.010 ± 0.005
N	0.36 ± 0.05*[b]	0.006*	1.67*[b]	-
Na	1.63 ± 0.10*	2.21 ± 0.27*	3.31 ± 0.03	2.31 ± 0.09
Nd	19 ± 1	-	-	-
Ni	20.4 ± 4.0	50.2 ± 5.0	7.87 ± 0.74	1.01 ± 0.08
Pb	23.6 ± 1.9	145 ± 5	4.2 ± 1.1	<1.7
Rb	74.2 ± 2.1	97.8 ± 3.9	<0.69	0.019 ± 0.008
S	0.44 ± 0.07*[b]	0.46*[b]	0.72*[b]	-
Sb	2.23 ± 0.26	-	0.089 ± 0.002	0.0041 ± 0.0001
Sc	6.47 ± 0.02	-	0.0022 ± 0.0001	-
Se	2.1 ± 0.7	2.2 ± 0.8	4.62 ± 0.03	0.581 ± 0.004
Si	15.4 ± 0.8*	21.9 ± 0.1*	<86	-
Sm	3.08 ± 0.06	-	0.0034 ± 0.0006	-
Sr	682 ± 19	958 ± 38	<1.2	<1.0
Ta	0.47 ± 0.03	-	-	-
Tb	0.40 ± 0.06	-	-	-
Th	6.70 ± 0.03	10.4 ± 2.0	0.011 ± 0.001	-
Ti	0.15 ± 0.01*	0.23 ± 0.01*	<1.6	<1.9
U	4.24 ± 0.20	-	0.118 ± 0.004	0.0011 ± 0.0001
V	104 ± 10	-	2.07 ± 0.09	<0.03
W	1.4 ± 0.2	-	-	0.0072 ± 0.0009
Y	13.3 ± 1.3	23.1 ± 1.3	<1.0	0.8 ± 0.7
Yb	1.36 ± 0.02	-	0.003 ± 0.001	0.0010 ± 0.0003
Zn	67.2 ± 2.6	353 ± 14	6.70 ± 0.16	0.62 ± 0.02

*Percent

[a] Data from L. Tripp (1979b).

[b] Data from Ackerman et al. (1979c).

Table 150

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Elemental abundances in products from run L-1 (ppm).

	Raw oil shale	Spent oil shale	Shale oil	Retort water
Al	4.04 ± 0.05*	5.64 ± 0.08*	-	-
As	37.3 ± 1.4	59.6 ± 2.4	8.19 ± 0.42	0.86 ± 0.01
Ba	498 ± 22	748 ± 18	-	-
C (org)	10.8 ± 2.8*	-	81.17*	0.20 ± 0.04*
C (inor)	4.73 ± 0.5*	-	-	1.24 ± 0.02*
Ca	8.82 ± 0.06*	14.3 ± 0.1*	-	<16
Cd	0.72 ± 0.07	-	-	-
Ce	43.6 ± 0.4	60.9 ± 0.9	-	0.007 ± 0.003
Cl	-	-	-	309 ± 3
Co	9.18 ± 0.12	12.9 ± 0.2	-	0.212 ± 0.002
Cr	37.3 ± 0.5	77.0 ± 1.0	-	0.43 ± 0.01
Cs	11.69 ± 0.33	6.69 ± 0.17	-	-
Cu	40.2 ± 3.0	38.6 ± 3.4	3.46 ± 0.56	<1.0
Dy	2.48 ± 0.05	3.45 ± 0.10	-	-
Eu	0.634 ± 0.007	0.894 ± 0.013	-	-
Fe	2.24 ± 0.07*	3.11 ± 0.06*	49.7 ± 2.4	1.7 ± 0.3
Ga	9.8 ± 1.8	12.6 ± 1.6	-	<0.6
Ge	<2.4	1.6 ± 1.2	-	<0.6
H	1.67 ± 0.08*	-	11.20*	-
Hf	1.71 ± 0.05	2.72 ± 0.06	-	0.0020 ± 0.0003
Hg	0.084 ± 0.006	0.001 ± 0.0002	0.084 ± 0.030	0.019 ± 0.004
K	1.70 ± 0.05*	2.34 ± 0.03*	-	18 ± 7
La	20.8 ± 0.4	31.0 ± 0.7	-	0.014 ± 0.016
Lu	0.189 ± 0.011	0.28 ± 0.02	-	-
Mg	3.43 ± 0.08*	5.37 ± 0.10*	-	<7.0
Mn	342 ± 7	490 ± 10	<2.3	0.172 ± 0.006
Mo	20.8 ± 1.4	30.6 ± 2.5	-	0.13 ± 0.02
N	0.51 ± 0.05*	-	1.56*	-
Na	1.63 ± 0.10*	2.41 ± 0.02*	-	179 ± 1
Nd	19 ± 1	25 ± 2	-	-
Ni	20.4 ± 4.0	33.2 ± 4.4	3.85 ± 0.64	<0.31
Pb	23.6 ± 1.9	62.0 ± 2.5	1.27 ± 1.04	<1.7
Rb	74.2 ± 2.1	100 ± 4	<0.69	<0.018
S	0.66 ± 0.07*	-	0.78*	-
Sb	2.23 ± 0.26	3.16 ± 0.20	-	0.081 ± 0.001
Sc	6.47 ± 0.02	8.64 ± 0.23	-	-
Se	2.1 ± 0.7	2.2 ± 0.8	1.04 ± 0.28	0.228 ± 0.005
Si	15.4 ± 0.8*	21.4 ± 0.1*	-	-
Sm	3.08 ± 0.06	4.30 ± 0.21	-	-
Sr	682 ± 19	1020 ± 20	-	<0.27
Ta	0.47 ± 0.03	3.50 ± 0.01	-	-
Tb	0.40 ± 0.06	0.56 ± 0.14	-	-
Th	6.70 ± 0.03	9.86 ± 0.07	-	<1.5
Ti	0.15 ± 0.01*	0.21 ± 0.05*	-	<3.5
U	4.24 ± 0.20	7.19 ± 0.06	-	0.195 ± 0.002
V	104 ± 10	152 ± 21	-	0.16 ± 0.04
W	1.4 ± 0.2	2.5 ± 0.9	-	0.13 ± 0.01
Y	13.3 ± 1.3	22.1 ± 1.2	-	<1.1
Yb	1.36 ± 0.02	1.99 ± 0.04	-	-
Zn	67.2 ± 2.6	173 ± 6	4.13 ± 0.46	0.58 ± 0.03

*Percent

Table 151

CS-60 mass balance (mg).

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	651	654	0.00043	-	-	100
As	710	766	10.3	0.470	-	107
Ba	8010	7920	1.20	-	-	99
C(org)(gm)	2700	1547	952	0.32	79.2	95
C(inor)(gm)	720	675	-	0.49	79.9	105
Ca (gm)	1560	1540	-	0.0019	-	100
Cd	15	16	-	0.0003	-	107
Ce	700	703	0.066	<0.0015	-	100
Cl	-	-	2.6	87.0	-	-
Co	168	168	2.64	0.0285	-	102
Cr	667	633	1.12	0.104	-	95
Cs	80.6	82.8	-	0.0010	-	103
Cu	622	653	0.70	0.011	-	105
Dy	37.9	37.3	0.0049	-	-	98
Eu	10.5	10.6	0.0012	<0.00003	-	101
Fe (gm)	353	351	0.084	0.0017	-	99
Ga	136	143	0.13	0.004	-	105
H (gm)	363	174	138	8.2	26.5	96
Hf	29.5	29.5	0.0018	-	-	100
Hg (ug)	2793	3138	<56	3.3	-	<114
K (gm)	259	258	0.0079	0.0014	-	100
La	345	346	0.043	0.0089	-	100
Lu	2.95	2.89	-	-	-	101
Mg (gm)	598	592	0.024	<0.0016	-	99
Mn	5087	5145	0.363	0.004	-	101
Mo	478	473	0.45	0.017	-	99
N (gm)	130	96	21	0.74	0.0	91
Na (gm)	314	322	0.066	0.062	-	103
Nd	291	289	-	-	-	99
Ni	353	375	8.48	0.403	-	109
Pb	426	478	<1.7	<0.018	-	112
Rb	1135	1174	<0.75	0.021	-	103
S (gm)	135	110	11.3	0.11	18.7	104
Sb	38.9	39.9	0.026	0.020	-	103
Sc	94.8	97.5	0.0043	-	-	101
Se	32.6	37.6	0.97	0.030	-	118
Si (gm)	2468	2489	<0.29	-	-	101
Sm	48.8	48.7	0.0048	-	-	100
Sr	10,670	10,995	0.85	0.033	-	103
Ta	7.54	7.58	-	-	-	101
Tb	6.12	5.94	-	-	-	97
Th	112	113	0.0080	<0.013	-	101
Ti (gm)	24	25	<0.001	<0.00004	-	104
U	85.0	84.8	0.049	0.0087	-	100
V	1846	1798	1.0	<0.011	-	97
W	29	28	-	-	-	97
Y	149	192	<1.1	<0.011	-	129
Yb	21.1	21.5	0.0048	-	-	102
Zn	1064	1103	3.60	0.081	-	106

Table 152

CS-61 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	669	668	0.034	-	-	100
As	443	458	29.0	0.953	-	110
Ba (gm)	10.1	10.3	0.0012	-	-	102
C (org)(gm)	1670	430	1227	0.34	91.7	105
C(inor)(gm)	1020	869	-	1.85	19.9	87
Ca (gm)	2230	2234	0.11	-	-	102
Cd	13	9.2	-	-	-	71
Ce	751	719	0.048	<0.002	-	96
Cl	-	-	6.0	81.5	-	-
Co	152	151	2.71	0.071	-	101
Cr	585	585	0.41	0.18	-	100
Cs	62.6	63.7	-	0.0036	-	102
Cu	587	590	2.6	<0.52	-	101
Dy	41.2	42.8	-	-	-	104
Eu	10.9	10.8	<0.0006	<0.00004	-	99
Fe (gm)	350	342	0.141	0.0013	-	98
Ga	140	154	<0.74	-	-	110
H (gm)	246	17.2	177	25.2	37.5	104
Hf	28.7	31.7	-	0.00050	-	110
Hg (ug)	1508	776	82	-	-	<60
K (gm)	304	293	-	-	-	96
La	354	354	0.034	0.0091	-	97
Lu	3.20	3.43	-	-	-	107
Mg (gm)	700	707	0.042	<0.002	-	101
Mn (gm)	6.18	6.06	0.00091	0.000029	-	98
Mo	343	331	0.23	0.02	-	97
N (gm)	101	46.3	22.8	4.2	1.3	74
Na (gm)	305	332	0.207	0.144	-	109
Nd	300	290	-	-	-	97
Ni	360	320	14.0	0.402	-	93
Pb	352	391	<2.3	-	-	111
Rb	1110	1115	<1.0	0.023	-	100
S (gm)	145	82.4	8.3	0.27	28.5	82
Sb	25.3	24.9	0.019	0.024	-	99
Sc	102	100	0.0050	-	-	98
Se	24	32	1.1	0.13	-	138
Si (gm)	2590	2564	<0.30	-	-	99
Sm	53.1	52.2	0.0047	-	-	98
Sr	14.5	15.7	6.73	-	-	108
Ta	7.90	7.81	-	-	-	99
Tb	7.2	7.0	-	-	-	96
Th	112	170	0.0061	0.00027	-	152
Ti (gm)	24.2	25.9	<0.0018	<0.001	-	107
U	62.6	103	0.044	0.0079	-	165
V	1490	1200	0.41	<0.012	-	81
W	26	23	-	-	-	88
Y	197	230	<1.5	-	-	117
Yb	21.2	25.2	-	-	-	119
Zn	1080	1110	6.32	-	-	103

Table 153

CS-62 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	518	538	0.0387	-	-	104
As	469	554	23.4	0.51	-	123
Ba	8960	8340	2.2	-	-	93
C (org)(gm)	2319	707	1673	0.94	148	109
C (inor)(gm)	875	768	-	1.62	166	107
Ca (gm)	1940	1982	-	0.0004	-	102
Cd	11	7.4	<0.03	0.00043	-	67
Ce	619	546	0.10	0.0003	-	89
Cl	-	-	10	26.1	-	-
Co	120	111	4.20	0.031	-	96
Cr	499	320	11.2	0.042	-	66
Cs	72.9	58.5	-	-	-	80
Cu	501	579	3.7	<0.007	-	116
Dy	32.4	29.1	0.0084	-	-	91
Eu	8.96	8.27	0.001	<0.00001	-	92
Fe (gm)	277	277	0.35	0.0011	-	100
Ga	110	115	0.17	0.004	-	105
H (gm)	310	28.9	237	29.1	54.2	113
Hf	24.5	24.1	-	-	-	98
Hg (μg)	1231	504	<171	3.6	-	<55
K (gm)	219	218	-	<0.0003	-	100
La	314	277	0.048	0.0039	-	88
Lu	2.53	2.18	-	-	-	86
Mg (gm)	616	622	0.059	0.0007	-	101
Mn (gm)	4.77	4.63	0.0028	0.0036	-	97
Mo	339	341	0.69	0.0074	-	101
N (gm)	106	69	41	3.8	0.3	108
Na (gm)	246	267	0.104	0.024	-	109
Nd	270	210	-	-	-	78
Ni	297	330	22.9	0.79	-	119
Pb	312	359	<3.5	<0.018	-	119
Rb	1040	981	<1.6	<0.011	-	94
S (gm)	105	80	12.2	2.23	30.5	119
Sb	26.1	27.1	0.041	0.0077	-	104
Sc	87.0	73.2	0.0074	-	-	84
Se	25	32	1.6	0.035	-	134
Si (gm)	2180	2150	<0.33	-	-	99
Sm	43.2	39.0	0.0061	-	-	90
Sr (gm)	13.3	13.9	0.0030	<0.0089	-	105
Ta	5.97	5.61	0.13	-	-	96
Tb	5.7	4.6	-	-	-	81
Th	91.9	73.0	0.0086	<0.013	-	79
Ti (gm)	20	19.8	<0.002	<0.00004	-	99
U	72.4	65.3	0.03	0.00027	-	90
V	1460	1640	1.8	<0.0042	-	112
W	19	14	-	0.004	-	74
Y	130	182	<2.2	<0.011	-	140
Yb	19.2	16.9	<0.006	<0.0008	-	88
Zn	889	885	8.78	0.084	-	101

Table 154

CS-53 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	1210	1170	0.0018	-	-	97
As	469	525	0.257	0.906	-	112
Ba	6210	5800	0.22	-	-	93
C (org)(gm)	1618	970	425	0.89	173.8	97
C(inor)(gm)	33	13	-	1.15	92.9	324
Ca (gm)	84.5	87.0	-	0.0069	-	103
Cd	11	5.2	< 0.011	< 0.0032	-	47
Ce	1310	1340	-	0.0069	-	102
Cl	-	-	9.4	192	-	-
Co	403	398	0.0081	0.013	-	99
Cr	1360	1330	0.075	0.04	-	98
Cs	118	119	-	0.040	-	101
Cu	1300	1300	< 0.40	0.17	-	100
Dy	101	99.1	-	-	-	98
Eu	24.8	25.0	< 0.00004	0.0001	-	101
Fe (gm)	769	765	0.0029	0.0014	-	99
Ga	264	271	0.030	0.03	-	103
H (gm)	213	51	53.9	58.1	75.8	112
Hf	79.7	79.3	-	0.0024	-	100
Hg (μg)	2279	1104	< 33	40	-	< 52
K (gm)	515	502	0.0028	0.0807	-	97
La	570	570	0.00011	0.004	-	100
Lu	7.88	6.72	-	-	-	85
Mg (gm)	188	182	0.0026	0.014	-	97
Mn	3220	3210	0.0861	< 0.010	-	100
Mo	1880	1880	0.019	1.41	-	100
N (gm)	88	50	3.8	5.9	0.0	68
Na (gm)	64.4	63.8	0.00036	0.0955	-	99
Nd	580	630	-	-	-	109
Ni	1330	1360	1.23	0.500	-	102
Pb	421	444	< 0.86	< 0.12	-	105
Rb	2160	2170	< 0.37	0.60	-	100
S (gm)	528	371	9.3	6.01	300	130
Sb	66.0	53.8	0.0038	0.455	-	82
Sc	239	235	-	-	-	98
Se	45	29	0.56	0.22	-	66
Si (gm)	4375	4180	< 0.05	0.0021	-	96
Sm	111	112	-	-	-	101
Sr	1210	1250	< 0.48	0.18	-	103
Ta	14.5	14.5	-	-	-	100
Th	15	16	-	-	-	107
Th	173	170	< 0.75	0.084	-	98
Ti (gm)	65	69	< 0.3	0.0034	-	100
U	476	462	0.00054	0.36	-	97
V	2580	2630	0.86	< 0.03	-	102
W	-	-	-	-	-	-
Y	513	538	0.54	< 0.074	-	105
Yb	54.5	53.6	-	-	-	98
Zn	651	684	3.77	0.46	-	106

Table 155

CS-64 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	527	490	0.0155	-	-	93
As	651	748	14.6	0.352	-	117
Ba	3590	6220	2.0	-	-	173
C (org)(gm)	3670	920	2596	1.32	239.3	102
C(inor)(gm)	409	262	-	2.17	174.3	107
Ca (gm)	752	810	-	0.0013	-	108
Cd	14.6	10.3	<0.047	0.00011	-	71
Ce	506	500	0.064	0.0013	-	99
Cl	-	-	22.0	34.6	-	-
Co	188	182	7.56	0.0293	-	101
Cr	493	508	0.68	0.0026	-	103
Cs	48.3	49.6	-	0.0039	-	103
Cu	702	753	<2.5	0.010	-	107
Dy	25.9	24.7	0.0047	-	-	95
Eu	7.56	7.30	-	<0.00001	-	97
Fe (gm)	302	301	0.231	0.00019	-	100
Ga	100	110	0.16	0.005	-	110
H (gm)	555	25	371	43.0	99.2	97
Hf	19.2	19.9	-	0.00012	-	104
Hg (µg)	3824	463	142	18	-	16
K (gm)	157	152	-	0.0004	-	97
La	276	259	0.030	<0.0016	-	94
Lu	1.49	1.81	-	-	-	121
Mg (gm)	415	389	0.022	0.0014	-	94
Mn	3010	3350	0.527	0.006	-	111
Mo	528	522	0.68	0.030	-	99
N (gm)	147	63	54	5.4	0.0	83
Na (gm)	340	338	0.117	0.116	-	99
Nd	240	240	-	-	-	100
Ni	368	387	14.6	0.216	-	109
Pb	513	559	<5.4	<0.022	-	109
Rb	909	919	<2.3	0.026	-	101
S (gm)	146	144	26	0.62	96.9	183
Sb	35.4	35.6	0.037	0.0139	-	101
Sc	73.7	76.0	0.0030	-	-	103
Se	35	48	2.0	0.026	-	143
Si (gm)	1933	1820	<0.32	-	-	94
Sm	34.7	34.0	0.0051	-	-	98
Sr	4640	3450	<2.9	<0.0031	-	117
Ta	5.79	5.63	-	-	-	97
Tb	4.1	3.9	-	-	-	95
Th	67.2	71.6	<4.4	<0.017	-	107
Ti (gm)	19.1	19.0	<0.0014	<0.00005	-	99
U	70.7	70.6	<7.8	0.0040	-	100
V	1850	2159	2.5	0.0058	-	117
W	36	24	-	-	-	67
Y	193	132	<3.4	0.011	-	68
Yb	14.0	14.4	-	-	-	103
Zn	974	1017	2.3	0.012	-	105

Table 156

CS-65 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	658	592	<0.0002	-	-	90
As	214	228	1.20	2.30	-	108
Ba	1600	1494	0.50	-	-	93
C (org, gm)	2060	965	873	5.18	151.3	97
C(inor, gm)	685	628	-	1.56	68.3	102
Ca (gm)	2040	1940	-	0.008	-	95
Cd	-	-	<0.016	0.0083	-	-
Ce	682	653	-	<0.010	-	96
Cl	-	-	11.2	321	-	-
Co	82.6	76.0	0.11	0.019	-	92
Cr	5160	4900	0.30	0.008	-	95
Cs	32.0	35.2	-	0.005	-	110
Cu	886	929	<1.1	0.18	-	105
Dy	61.9	60.0	0.016	-	-	97
Eu	17.1	16.3	-	<0.0002	-	95
Fe (gm)	325	305	0.024	0.0019	-	94
Ga	130	120	0.15	0.07	-	92
H (gm)	282	40	119	108.4	68.4	119
Hf	44.8	43.1	-	-	-	96
Hg (ug)	1598	380	66	297	-	46
K (gm)	120	113	0.0040	0.056	-	94
La	389	358	0.0048	0.003	-	92
Lu	6.34	5.51	-	-	-	87
Mg (gm)	353	346	0.0073	0.022	-	98
Mn	1740	1740	0.13	<0.02	-	100
Mo	831	828	0.19	0.27	-	100
N (gm)	98	63	14	8.0	0.0	87
Na (gm)	18.7	18.1	0.012	0.183	-	98
Nd	360	420	-	-	-	117
Ni	2010	2000	10.0	2.41	-	100
Pb	54	90	<2.0	<0.22	-	167
Rb	617	620	<0.84	0.32	-	101
S (gm)	215	103	76	7.13	179.5	170
Sb	27.5	29.0	0.01	0.331	-	107
Sc	166	157	0.0004	-	-	95
Se	261	260	16.1	4.95	-	108
Si (gm)	1950	1810	0.14	0.0078	-	93
Sm	60.1	56.4	0.0006	0.11	-	94
Sr	6260	6210	0.16	0.012	-	99
Ta	7.66	7.56	-	-	-	99
Tb	8.7	8.9	-	-	-	102
Th	85.0	78.3	<1.7	<0.17	-	92
Ti (gm)	31.6	28.0	<0.001	<0.00056	-	89
U	438	430	0.011	0.264	-	98
V	2360	2180	4.73	<0.035	-	93
W	-	-	-	-	-	-
Y	508	518	<1.2	<0.14	-	102
Yb	40.5	40.4	-	-	-	100
Zn	5000	5340	2.18	0.79	-	107

Table 157

CS-[illegible] mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	562	623	0.0787	-	-	111
As	667	718	21.1	4.06	-	111
Ba	6920	7480	4.5	0.078	-	108
C (org)(gm)	2194	500	1496	3.09	127.8	97
C(inor)(gm)	779	503	-	6.17	363.8	112
Ca (gm)	1670	1540	0.17	0.0078	-	92
Cd	12	9.4	-	0.001	-	78
Ce	634	669	0.17	0.003	-	106
Cl	-	-	8.6	91.7	-	-
Co	141	143	6.07	0.217	-	106
Cr	498	537	0.58	0.013	-	108
Cs	80.0	89.5	-	0.015	-	112
Cu	589	596	<1.5	0.064	-	101
Dy	34.6	35.1	0.022	-	-	102
Eu	8.82	9.78	0.0039	<0.00003	-	111
Fe (gm)	291	322	0.14	0.00067	-	111
Ga	116	143	-	<0.020	-	123
H (gm)	428[a]	30	203	79.7	58.1	87
Hf	25.6	29.4	-	0.0022	-	115
Hg (ug)	1525	197	<176	54	-	<28
K (gm)	213	222	0.058	0.018	-	104
La	308	324	0.22	0.0051	-	105
Lu	2.20	2.33	-	-	-	106
Mg (gm)	562	589	0.14	0.0051	-	105
Mn	4720	4880	1.70	0.020	-	103
Mo	380	381	<3.9	0.453	-	100
N (gm)	94	39	34	12	0.0	90
Na (gm)	284	311	0.56	0.539	-	110
Nd	280	270	-	-	-	96
Ni	313	316	16.6	1.06	-	107
Pb	348	391	<3.4	<0.081	-	112
Rb	1020	1060	<1.5	0.22	-	104
S (gm)	89	80	9.9	0.72	43.2	150
Sb	33.9	29.9	0.065	0.0852	-	89
Sc	83.8	89.6	0.0086	-	-	107
Se	31	38	2.0	0.14	-	129
Si (gm)	2180	2320	0.49	-	-	106
Sm	43.1	45.4	0.030	-	-	105
Sr (gm)	11.7	11.3	<0.0019	0.00011	-	97
Ta	6.75	7.41	-	-	-	110
Tb	5.1	5.5	-	-	-	108
Th	90.5	95.2	0.02	0.0025	-	105
Ti (gm)	20	23	<0.005	0.00020	-	115
U	71.5	73.1	<4.9	0.042	-	102
V	1180	1610	2.34	<0.021	-	137
W	18	28	-	-	-	156
Y	140	198	<2.2	<0.051	-	141
Yb	18.2	19.8	-	0.00071	-	109
Zn	954	1020	0.86	0.054	-	107

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[a] Includes 69 gm H in input steam.

Table 158

CS-67 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	476	456	0.033	-	-	96
As	590	690	14.1	1.35	-	120
Ba	3740	3820	2	0.055	-	102
C (org)(gm)	365-	879	2517	3.63	227.6	94
C(inor)(gm)	425	249	-	4.65	225.2	136
Ca (gm)	805	775	-	0.002	-	96
Cd	16.7	13.4	<0.05	0.00027	-	80
Ce	498	453	0.038	<0.0039	-	91
Cl	-	-	51.1	128	-	-
Co	186	170	6.76	0.0838	-	95
Cr	464	449	0.75	0.0043	-	97
Cs	43.2	42.7	-	0.026	-	99
Cu	714	691	<2.5	<0.04	-	97
Dy	23.9	19.9	0.003	-	-	83
Eu	6.75	6.44	-	<0.00008	-	95
Fe (gm)	271	273	0.20	0.476	-	101
Ga	90	104	0.12	<0.02	-	116
H (gm)	586[a]	32	352	93.8	102.8	99
Hf	18.6	18.1	-	0.00055	-	97
Hg (μg)	4296	404	201	37	-	15
K (gm)	141	140	0.017	0.002	-	99
La	251	228	0.022	0.013	-	91
Lu	1.45	1.49	-	-	-	103
Mg (gm)	400	377	0.028	0.0067	-	94
Mn	3050	3090	0.53	<0.039	-	101
Mo	44-	429	0.51	0.21	-	97
N (gm)	127	59	57	10	0	99
Na (gm)	329	314	0.18	0.535	-	96
Nd	210	160	-	-	-	76
Ni	338	336	14.1	0.503	-	104
Pb	498	511	<5.5	<0.094	-	103
Rb	789	840	<2.4	0.11	-	106
S (gm)	354	167	24	1.18	94.6	81
Sb	34.9	35.7	0.02	0.0582	-	103
Sc	73.9	70.1	0.0030	-	-	95
Se	33	41	2.8	0.492	-	134
Si (gm)	1800	1710	<0.27	-	-	95
Sm	31.9	29.4	0.003	0.0003	-	92
Sr	4880	5080	<3.0	0.000039	-	104
Ta	5.41	5.23	-	-	-	97
Th	3.5	3.1	-	-	-	89
Th	65.0	60.2	<4.8	0.0003	-	93
Ti (gm)	18	18	<0.002	<0.00024	-	100
U	66.8	59.4	<7.8	0.018	-	89
V	2320	2110	2.0	<0.028	-	91
W	20	28	-	-	-	140
Y	50	120	<3.4	<0.059	-	240
Yb	13.4	13.0	-	-	-	97
Zn	967	927	2.4	0.04	-	96

[a] Includes 64 gm H in input steam.

Table 159

CS-68 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	634	592	0.035	-	-	93
As	681	619	27.8	2.43	-	95
Ba	7520	7624	2.7	0.076	-	101
C (org)(gm)	1836	571	1460	1.42	110.1	117
C(inor)(gm)	775	640	-	2.93	156.9	103
Ca (gm)	1610	1510	-	0.0032	-	94
Cd	12	8.4	<0.027	0.00038	-	70
Ce	702	648	0.11	0.0016	-	92
Cl	-	-	4.7	50.9	-	-
Co	154	137	6.01	0.0973	-	93
Cr	549	526	0.31	0.0079	-	96
Cs	88.7	89.6	-	0.0056	-	101
Cu	567	563	<1.5	0.024	-	99
Dy	36.7	34.2	0.01	-	-	93
Eu	10.6	9.91	0.002	0.00003	-	94
Fe (gm)	336	311	0.15	0.539	-	93
Ga	130	135	<1.0	0.01	-	104
H (gm)	223	37	205	42.7	44.8	147
Hf	27.6	28.6	-	0.00052	-	104
Hg (μg)	1300	361	76	24	-	36
K (gm)	241	219	-	0.0070	-	91
La	343	323	0.084	-	-	94
Lu	2.99	2.49	-	-	-	83
Mg (gm)	590	572	0.084	0.0030	-	97
Mn	5010	4770	1.02	<0.01	-	95
Mo	388	370	-	0.22	-	95
N (gm)	91	47	35	6.5	0.0	97
Na (gm)	317	296	0.27	0.282	-	94
Nd	280	250	-	-	-	89
Ni	333	327	15.8	0.591	-	103
Pb	335	370	<3.1	<0.038	-	110
Rb	1060	1020	<1.4	0.097	-	96
S (gm)	75	50	11	0.46	34.1	127
Sb	32.3	29.9	0.031	0.040	-	93
Sc	94.6	89.3	0.0055	-	-	94
Se	29	35	1.8	0.11	-	127
Si (gm)	2400	2240	<0.18	-	-	93
Sm	47.6	44.9	0.011	0.00027	-	94
Sr (gm)	11.1	11.2	<0.0017	0.000033	-	101
Ta	7.75	7.23	-	0.0081	-	93
Tb	5.4	5.4	-	-	-	100
Th	106	98.2	0.008	0.00073	-	93
Ti (gm)	28	24	<0.002	0.00010	-	86
U	77.4	70.8	<4.5	0.018	-	91
V	2020	1630	2.00	0.030	-	81
W	29	23	-	-	-	79
Y	180	193	<2.0	0.024	-	107
Yb	21.0	20.1	-	-	-	96
Zn	982	976	1.6	0.024	-	100

Table 160

CS-69 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	622	609	0.0433	-	-	98
As	690	725	19.7	2.20	-	108
Ba	7850	7850	3.8	-	-	100
C (org)(gm)	2151	294	1534	2.04	159.9	93
C(inor)(gm)	827	88	-	10.8	1160.3	152
Ca (gm)	1360	1630	-	0.0069	-	120
Cd	15	5.6	<0.031	0.00042	-	37
Ce	685	671	0.042	-	-	98
Cl	-	-	5.1	115	-	-
Co	159	138	6.36	0.228	-	91
Cr	583	538	0.33	0.021	-	92
Cs	89.9	92.6	-	0.015	-	103
Cu	612	582	<1.6	<0.03	-	95
Dy	38.3	35.4	0.011	-	-	92
Eu	10.1	10.1	0.00078	<0.00004	-	100
Fe (gm)	328	320	0.12	0.00159	-	98
Ga	147	140	0.2	<0.02	-	92
H (gm)	367[a]	1.1	210	80.8	105.0	108
Hf	27.1	28.3	0.02	0.00056	-	104
Hg (ug)	1458	182	121	36	-	23
K (gm)	232	230	0.016	0.013	-	99
La	349	336	0.038	0.019	-	96
Lu	2.56	2.71	-	-	-	106
Mg (gm)	593	580	0.068	0.0077	-	98
Mn	5030	5160	0.92	<0.02	-	103
Mo	485	373	0.85	0.26	-	77
N (gm)	97	1.7	36	22	1.6	63
Na (gm)	327	295	0.054	0.518	-	90
Nd	250	259	-	-	-	104
Ni	344	326	14.8	0.633	-	99
Pb	395	371	<3.6	<0.084	-	94
Rb	1050	1070	<1.5	0.18	-	102
S (gm)	83	63	12	.40	50.8	152
Sb	33.9	28.8	0.04	0.110	-	85
Sc	94.3	92.5	0.0025	-	-	98
Se	39	41	1.9	0.21	-	111
Si (gm)	2320	2295	<0.31	0.0041	-	99
Sm	48.1	47.0	0.0047	0.0002	-	98
Sr (gm)	11.4	11.4	0.0014	0.000074	-	100
Ta	7.43	7.33	-	-	-	99
Tb	6.3	5.8	-	-	-	92
Th	101	100	<3.1	0.00056	-	99
Ti (gm)	23	23	<0.0013	<0.00024	-	100
U	76.0	73.9	<5.1	0.026	-	97
V	1710	1600	1.65	0.025	-	94
W	24	20	-	0.077	-	83
Y	150	220	<2.2	<0.053	-	147
Yb	20.9	20.3	-	0.00046	-	97
Zn	973	1010	1.5	0.035	-	104

[a] Includes 69 gm H in input steam.

Table 161

CJ-70 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	615	592	<0.0009	-	-	96
As	777	731	18.7	3.30	-	97
Ba	8480	7830	-	0.23	-	92
C (org)(gm)	2570	544	1676	3.22	193.5	94
C(inor)(gm)	845	571	-	6.06	335.5	108
Ca (gm)	1910	1720	-	0.0096	-	90
Cd	14	10	<0.033	0.00044	-	71
Ce	622	647	0.064	0.0037	-	104
Cl	-	-	-	124	-	-
Co	155	151	6.13	0.188	-	101
Cr	573	593	0.85	0.022	-	104
Cs	69.5	80.9	-	0.017	-	116
Cu	587	639	<1.7	<0.04	-	107
Dy	34.8	36.6	-	-	-	105
Eu	9.63	9.72	-	<0.00004	-	101
Fe (gm)	326	328	0.15	0.00181	-	101
Ga	140	130	<1.1	0.02	-	93
H (gm)	427[c]	33	243	85.1	75.9	102
Hf	24.5	27.0	-	0.0020	-	110
Hg (ug)	1077	91	68	39	-	18
K (gm)	240	228	-	0.014	-	95
La	323	323	0.094	-	-	100
Lu	2.54	2.47	-	-	-	97
Mg (gm)	606	570	0.069	<0.011	-	94
Mn	4990	4910	0.83	<0.02	-	98
Mo	445	456	1.39	0.26	-	103
N (gm)	111	46	39	11	0.0	86
Na (gm)	294	314	0.29	0.515	-	107
Nd	280	250	-	-	-	89
Ni	349	332	16.2	0.811	-	100
Pb	370	390	<3.5	<0.096	-	105
Rb	994	999	<1.6	0.20	-	101
S (gm)	97	56	13	0.84	47.1	121
Sb	34.9	35.3	0.052	0.0634	-	101
Sc	96.4	91.2	0.0045	-	-	95
Se	28	37	2.2	0.23	-	141
Si (gm)	2280	2250	0.22	-	-	99
Sm	45.7	46.1	0.0047	-	-	101
Sr (gm)	12.7	11.8	<0.0028	0.000084	-	93
Ta	6.85	6.95	-	-	-	101
Tb	5.6	5.5	-	-	-	98
Th	104	101	<3.1	0.0038	-	97
Ti (gm)	24	22	<0.003	0.00033	-	92
U	77.7	73.9	<5.4	0.033	-	95
V	2050	1680	2.1	<0.10	-	82
W	38	26	-	-	-	68
Y	150	196	<2.4	<0.06	-	131
Yb	21.0	20.5	-	0.00084	-	98
Zn	1030	1060	1.2	0.10	-	103

[c] Includes 67 gm H from input steam.

Table 162

CS-71 mass balances

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	501	502	0.00477	-	-	100
As	616	565	21.7	1.54	-	95
Ba	-	-	-	-	-	-
C (org)(gm)	2456	532	1642	4.33	164.0	95
C(inor)(gm)	855	647	-	4.10	291.4	110
Ca (gm)	2010	1910	0.19	0.0050	-	95
Cd	-	-	-	-	-	-
Ce	-	-	-	-	-	-
Cl	-	-	-	-	-	-
Co	-	-	-	-	-	-
Cr	-	-	-	-	-	-
Cs	-	-	-	-	-	-
Cu	554	527	2.1	<0.03	-	95
Dy	-	-	-	-	-	-
Eu	-	-	-	-	-	-
Fe (gm)	285	276	0.14	0.00118	-	97
Ga	-	-	-	-	-	-
H (gm)	378	28.4	144	85.9	69.4	113
Hf	-	-	-	-	-	-
Hg (ug)	1185	676	308	17	-	84
K (gm)	205	192	0.062	0.0064	-	94
La	-	-	-	-	-	-
Lu	-	-	-	-	-	-
Mg (gm)	635	582	0.21	<0.0034	-	92
Mn	4420	4630	1.48	<0.007	-	105
Mo	-	-	-	-	-	-
N (gm)	139	34	[illegible]	8.9	0	58
Na (gm)	232	230	[illegible]	0.090	-	99
Nd	-	-	-	-	-	-
Ni	344	324	3.46	0.656	-	97
Pb	350	349	3.8	<0.070	-	100
Rb	1020	981	1.7	0.057	-	96
S (gm)	71	38	15	0.70	35.9	126
Sb	-	-	-	-	-	-
Sc	-	-	-	-	-	-
Se	30	30	1.3	0.11	-	105
Si (gm)	2130	2060	<0.21	-	-	97
Sm	-	-	-	-	-	-
Sr (gm)	13.7	13.4	0.0024	0.000070	-	98
Ta	-	-	-	-	-	-
Tb	-	-	-	-	-	-
Th	-	-	-	-	-	-
Ti (gm)	19	19	0.003	<0.00019	-	100
U	-	-	-	-	-	-
V	-	-	-	-	-	-
W	-	-	-	-	-	-
Y	150	182	<2.6	<0.050	-	121
Yb	-	-	-	-	-	-
Zn	855	851	1.1	0.047	-	100

Table 163

CS-72 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	628	628	-	-	-	100
As	467	475	20.0	1.69	-	106
Ba	-	-	-	-	-	-
C (org)(gm)	1640	320	1223	3.02	108.9	101
C(inor)(gm)	1010	711	-	7.32	430.7	114
Ca (gm)	2030	2180	-	-	-	107
Cd	-	-	-	-	-	-
Ce	-	-	-	-	-	-
Cl	-	-	-	-	-	-
Co	-	-	-	-	-	-
Cr	-	-	-	-	-	-
Cs	-	-	-	-	-	-
Cu	558	560	<1.4	<0.28	-	100
Dy	-	-	-	-	-	-
Eu	-	-	-	-	-	-
Fe (gm)	354	343	0.045	0.00070	-	97
Ga	130	140	<0.91	<0.18	-	108
H (gm)	256[a]	24	170	83.1	46.9	127
Hf	-	-	-	-	-	-
Hg (μg)	1293	430	-	12	-	-
K (gm)	294	279	-	-	-	95
La	-	-	-	-	-	-
Lu	-	-	-	-	-	-
Mg (gm)	663	654	-	-	-	99
Mn	5870	5910	<4.2	-	-	101
Mo	-	-	-	-	-	-
N (gm)	55	41	31	13	0.16	155
Na (gm)	272	282	-	-	-	104
Nd	-	-	-	-	-	-
Ni	305	297	15.1	0.589	-	103
Pb	325	360	<3.0	0.50	-	111
Rb	1110	1070	<1.3	0.24	-	96
S (gm)	74	49	8.9	0.53	37.2	129
Sb	-	-	-	-	-	-
Sc	-	-	-	-	-	-
Se	24	28	1.2	0.17	-	122
Si (gm)	2480	2430	-	-	-	98
Sm	-	-	-	-	-	-
Sr (gm)	15.2	15.0	<0.0023	0.00027	-	99
Ta	-	-	-	-	-	-
Tb	-	-	-	-	-	-
Th	-	-	-	-	-	-
Ti (gm)	25	24	<0.016	0.00044	-	96
U	-	-	-	-	-	-
V	-	-	-	-	-	-
W	-	-	-	-	-	-
Y	185	226	<1.9	<0.32	-	122
Yb	-	-	-	-	-	-
Zn	1060	1080	1.1	<0.21	-	102

[a] Includes 71 gm H from input steam.

Table 164

CS-73 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	580	585	-	-	-	101
As	238	238	4.17	2.75	-	101
Ba	-	-	-	-	-	-
C (org)(gm)	2045	881	898	7.52	143.0	94
C(inor)(gm)	672	632	-	4.29	121.4	112
Ca (gm)	1980	1985	-	-	-	100
Cd	-	-	-	-	-	-
Ce	-	-	-	-	-	-
Cl	-	-	-	-	-	-
Co	-	-	-	-	-	-
Cr	-	-	-	-	-	-
Cs	-	-	-			
Cu	914	952	<1.8	<1.1		104
Dy	-	-	-	-	-	
Eu	-	-	-	-	-	
Fe (gm)	309	323	0.027	0.0020	-	105
Ga	120	120	<1.1	0.65	-	101
H (gm)	376[a]	44	116	132.4	73.1	97
Hf	-	-	-	-	-	-
Hg (µg)	2029	374	<128	272	-	<38
K (gm)	121	123	-	-	-	102
La	-	-	-	-	-	-
Lu	-	-	-	-	-	-
Mg (gm)	313	379	-	-	-	121
Mn	1750	1570	<6.2	-	-	90
Mo	-	-	-	-	-	-
N (gm)	88	40	17	15	0	82
Na (gm)	192	<48	-	-	-	-
Nd	-	-	-	-	-	-
Ni	2010	2020	9.87	4.65	-	101
Pb	47	100	<3.3	<1.8	-	213
Rb	632	623	<1.5	0.78	-	99
S (gm)	293	102	73	9.3	181.9	125
Sb	-	-	-	-	-	-
Sc	-	-	-	-	-	-
Se	280	268	15	8.41	-	104
Si (gm)	1870	1830	-	-	-	98
Sm	-	-	-	-	-	-
Sr	6360	6290	<1.5	<0.0010	-	99
Ta	-	-	-	-	-	-
Tb	-	-	-	-	-	-
Th	-	-	-	-	-	-
Ti (gm)	33	31	<0.031	<0.024	-	94
U	-	-	-	-	-	-
V	-	-	-	-	-	-
W	-	-	-	-	-	-
Y	499	521	<1.8	<1.2	-	104
Yb	-	-	-	-	-	-
Zn	5290	5450	1.1	<0.81	-	103

[a] Includes 87 gm H from input steam.

Table 165

CS-74 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	630	686	-	-	-	109
As	456	509	24.1	2.13	-	117
Ba	-	-	-	-	-	-
C (org)(gm)	1750	44	1256	3.37	101.4	80
C(inor)(gm)	1056	79	-	14.8	1205	123
Ca (gm)	2260	20.80	-	-	-	92
Cd	-	-	-	-	-	-
Ce	-	-	-	-	-	-
Cl	-	-	-	-	-	-
Co	-	-	-	-	-	-
Cr	-	-	-	-	-	-
Cs	-	-	-	-	-	-
Cu	620	638	<1.4	<0.52	-	103
Dy	-	-	-	-	-	-
Eu	--	-	-	-	-	-
Fe (gm)	346	370	0.058	0.0023	-	107
Ga	150	160	<1.2	<0.25	-	107
H (gm)	369[a]	T	175	116.9	75.3	99
Hf	-	-	-	-	-	-
Hg (μg)	1490	225	-	12	-	-
K (gm)	289	325	-	-	-	112
La	-	-	-	-	-	-
Lu	-	-	-	-	-	-
Mg (gm)	668	700	-	-	-	105
Mn	-	-	-	-	-	-
Mo	-	-	-	-	-	-
N (gm)	77	17	33	30	2.1	107
Na (gm)	296	262	-	-	-	89
Nd	-	-	-	-	-	-
Ni	270	364	15	1.11	-	141
Pb	315	377	<3.0	<0.91	-	120
Rb	1110	1180	<1.4	0.32	-	106
S (gm)	107	68	8.5	0.53	31.0	101
Sb	-	-	-	-	-	-
Sc	-	-	-	-	-	-
Se	34	41	1.7	0.693	-	128
Si (gm)	2470	2570	-	-	-	104
Sm	-	-	-	-	-	-
Sr (gm)	15.4	14.3	<0.0018	0.00039	-	93
Ta	-	-	-	-	-	-
Tb	-	-	-	-	-	-
Th	-	-	-	-	-	-
Ti (gm)	25	27	<0.018	0.011	-	108
U	-	-	-	-	-	-
V	-	-	-	-	-	-
W	-	-	-	-	-	-
Y	200	275	<1.8	<0.59	-	138
Yb	-	-	-	-	-	-
Zn	1050	1130	1.2	<0.39	-	108

[a] Includes 119 gm H from input steam.

Table 166

S-7 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	5130	4980	-	-	-	97
As	4740	5240	-	-	-	-
Ba (gm)	63.3	62.0	-	-	-	98
C (org)(gm)	13,730	79	-	-	-	-
C(inor)(gm)	6010	2965	-	-	-	-
Ca (gm)	11,210	11,290	-	-	-	101
Cd	92	85	-	-	-	92
Ce	5540	5500	-	-	-	99
Cl	-	-	-	-	-	-
Co	1170	1160	-	-	-	99
Cr	4740	4560	-	-	-	96
Cs	596	632	-	-	-	106
Cu	5110	5120	-	-	-	100
Dy	315	302	-	-	-	96
Eu	80.6	78.9	-	-	-	98
Fe (gm)	2850	2580	-	-	-	91
Ga	1240	1280	-	-	-	103
H (gm)	2120	1374	-	-	-	-
Hf	231	238	-	-	-	103
Hg (μg)	10,680	-	-	-	-	-
K (gm)	2160	2120	-	-	-	98
La	2640	2740	-	-	-	103
Lu	24.0	20.3	-	-	-	85
Mg (gm)	4360	4420	-	-	-	101
Mn (gm)	43.5	40.6	-	-	-	93
Mo	2640	3260	-	-	-	123
N (gm)	650	-	-	-	-	-
Na (gm)	1980	2210	-	-	-	107
Nd	2410	2360	-	-	-	98
Ni	2590	3540	-	-	-	137
Pb	3000	3960	-	-	-	132
Rb	9320	9230	-	-	-	99
S (gm)	840	-	-	-	-	-
Sb	283	277	-	-	-	98
Sc	822	744	-	-	-	91
Se	267	344	-	-	-	129
Si (gm)	19,570	18,950	-	-	-	98
Sm	394	391	-	-	-	100
Sr (gm)	86.7	86.0	-	-	-	99
Ta	60.2	59.9	-	-	-	100
Tb	51	46	-	-	-	90
Th	852	855	-	-	-	100
Ti (gm)	190	190	-	-	-	100
U	539	573	-	-	-	106
V (gm)	13.2	12.4	-	-	-	94
W	180	180	-	-	-	100
Y	1640	1740	-	-	-	103
Yb	173	179	-	-	-	103
Zn	8410	10,900	-	-	-	-

Table 167

S-9 mass [illegible]ance (mg).

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
l (gm)	5070	5070	0.006	0.0271	-	100
As	4680	5140	130	0.80	-	113
Ba (gm)	62.5	64.6	-	-	-	103
C (org)(gm)	13,39	2921	9795	5.3	584	98
C(inor)(gm)	5940	5900	-	5.6	401	106
Ca (gm)	11,1[illegible]	11,360	-	-	-	102
Cd	90	94	<0.12	<0.003	-	104
Ce	5480	5260	-	-	-	96
Cl	-	-	1045	<9	-	-
Co	1150	1140	14.0	<0.05	-	100
Cr	4680	4210	0.7	<0.7	-	90
Cs	590	600	-	-	-	98
Cu	5050	5790	38	5.6	-	116
Dy	310	294	-	-	-	95
Eu	79.6	76.6	-	-	-	96
Fe (gm)	2809	2525	0.45	0.00235	-	90
Ga	1230	1270	<0.9	-	-	103
H (gm)	2100	303	1388	189	287	103
Hf	215	687	-	-	-	320
Hg (ug)	10,550	3895	743	135	-	45
K (gm)	2140	2080	-	-	-	97
La	2610	2580	0.03	-	-	99
Lu	23.7	15.0	-	-	-	63
Mg (gm)	4310	4650	0.021	<0.068	-	108
Mn (gm)	43.0	39.8	0.0015	0.00038	-	93
Mo	261[illegible]	2710	3.2	-	-	104
N (gm)	640	H	225	-	-	-
Na (gm)	2050	2240	0.091	0.081	-	109
Nd	2390	1840	-	-	-	77
Ni	2540	3240	49	0.41	-	128
Pb	2940	3550	17	0.1	-	121
Rb	9320	9440	<0.7	-	-	101
S (gm)	830	325	84	-	-	-
Sb	280	252	0.27	-	-	90
Sc	813	726	0.008	-	-	89
Se	264	368	10	0.51	-	143
Si (gm)	19,340	19,370	-	-	-	100
Sm	387	370	0.005	-	-	96
Sr (gm)	85.[illegible]	85.9	<0.0064	-	-	100
Ta	59.5	72.4	-	-	-	122
Tb	50	49	-	-	-	98
Th	842	830	0.07	<0.02	-	99
Ti (gm)	188	190	<0.003	<0.0041	-	101
U	532	723	0.08	-	-	136
V (gm)	13.[illegible]	11.6	0.0035	0.0002	-	89
W	180	-	-	-	-	-
Y	1670	1790	12	-	-	108
Yb	171	172	-	-	-	101
Zn	8440	9630	35	0.17	-	115

Table 168

S-10 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	5020	5040	-	0.060	-	100
As	4640	6560	216	6.20	-	146
Ba (gm)	61.9	61.7	-	-	-	100
C (org)(gm)	13,558[a]	29	9860	13	393	76
C(inor)(gm)	9212[b]	345	-	64.9	10,641	120
Ca (gm)	10,970	10,360	-	0.02	-	94
Cd	90	73	0.35	<0.007	-	82
Ce	5420	5700	-	-	-	105
Cl	-	-	9820	<22	-	-
Co	1140	1180	12.6	<3.0	-	105
Cr	4640	4440	0.8	<1.0	-	96
Cs	583	554	-	-	-	95
Cu	5000	4870	133	3.2	-	100
Dy	308	296	-	-	-	96
Eu	78.8	83.3	-	-	-	106
Fe (gm)	2780	2640	0.570	0.00863	-	95
Ga	1220	1200	<1.2	<0.22	-	98
H (gm)	2189[c]	17	1315	410	255	91
Hf	213	256	-	<0.44	-	120
Hg (ug)	10,448	<864	1722	<2	-	<25
K (gm)	2110	2080	-	0.02	-	99
La	2590	2850	-	-	-	110
Lu	23.5	20.2	-	-	-	86
Mg (gm)	4270	4050	-	-	-	95
Mn (gm)	42.5	40.3	0.0025	0.0014	-	95
Mo	2590	2680	-	-	-	103
N (gm)	634	130	240	-	-	-
Na (gm)	2030	2240	0.18	0.17	-	110
Nd	2360	2330	-	-	-	99
Ni	2540	2900	47	<1.8	-	116
Pb	2935	3000	28	<0.89	-	103
Rb	9230	8980	-	<0.33	-	97
S (gm)	521	259	88	-	-	-
Sb	277	260	0.24	-	-	94
Sc	805	759	-	-	-	94
Se	261	259	7.7	2.8	-	103
Si (gm)	19,150	19,100	-	-	-	100
Sm	383	390	-	-	-	102
Sr (gm)	84.8	83.1	<0.0015	0.00044	-	98
Ta	59.0	63.0	-	-	-	107
Tb	49.8	48.4	-	-	-	97
Th	833	858	0.03	<0.66	-	103
Ti (gm)	187	210	<0.11	<0.0021	-	107
U	527	560	-	<1.1	-	106
V (gm)	12.9	11.1	0.0047	0.0003	-	86
W	170	170	-	-	-	100
Y	1650	1650	<1.5	<0.55	-	100
Yb	169	171	-	-	-	101
Zn	8360	8430	22	0.89	-	101

[a] Includes 128 gm organic C in input gas.

[b] Includes 3332 gm inorganic C in input gas.

[c] Includes 2.109 gm H in input steam.

Table 169

S-11 mass balan [illegible]

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	5060	4820	0.0059	0.0421	-	95
As	4610	4750	150	8.66	-	105
Ba (gm)	62.3	61.5	<0.005	-	-	99
C (org)(gm)	13,520	6	9020	7.1	757	72
C(inor)(gm)	5946[a]	180	-	40.4	8914	154
Ca (gm)	11,040	10,520	-	0.071	-	95
Cd	90	66	0.27	-	-	74
Ce	5460	5390	-	-	-	99
Cl	-	-	38.3	37	-	-
Co	1150	1080	3.8	<0.10	-	94
Cr	4670	5100	1.5	1.3	-	109
Cs	587	593	-	-	-	101
Cu	5030	4720	27	448	-	103
Dy	310	312	-	-	-	101
Eu	79.4	79.6	<0.01	-	-	100
Fe (gm)	2800	2640	0.44	0.0916	-	94
Ga	1230	1090	<1.1	<0.30	-	89
H (gm)	2130[b]	26	1200	374	313	90
Hf	214	243	-	-	-	114
Hg (ug)	10,508	94	2408	286	-	27
K (gm)	2130	2140	-	0.088	-	100
La	2600	2730	<0.03	-	-	105
Lu	23.7	27.4	-	-	-	116
Mg (gm)	4290	4040	-	<0.13	-	94
Mn (gm)	42.8	41.2	0.00043	0.00064	-	96
Mo	2600	2370	9.4	-	-	92
N (gm)	640	[illegible]	190	-	-	-
Na (gm)	2040	2090	0.0084	0.18	-	102
Nd	2380	2140	-	-	-	90
Ni	2550	2620	32	5.29	-	104
Pb	2950	3180	16	3.87	-	108
Rb	9290	9405	<0.5	0.2	-	101
S (gm)	830	257	94	-	-	-
Sb	279	262	0.3	<0.2	-	94
Sc	810	793	0.004	-	-	98
Se	263	188	32	3.67	-	85
Si (gm)	19,280	18,550	-	-	-	96
Sm	386	384	0.21	-	-	100
Sr (gm)	85.4	80.7	<0.0095	<0.00040	-	94
Ta	59.3	59.0	-	-	-	99
Tb	50	51	-	-	-	102
Th	839	842	<0.007	<0.03	-	100
Ti (gm)	190	200	<0.0034	0.0029	-	105
U	531	541	-	<1.0	-	102
V (gm)	13.0	12.1	0.0032	0.0003	-	93
W	180	150	-	-	-	83
Y	1660	1830	<1.5	<0.51	-	110
Yb	170	180	-	-	-	106
Zn	8410	9920	59	44.8	-	119

[a] Includes 26 gm of inorganic C in input gas.

[b] Includes 39 gm of H in input steam.

Table 170

S-12 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure %
Al (gm)	5920	5610	0.016	-	-	95
As	5470	5630	69.6	8.67	-	104
Ba (gm)	71.0	68.8	-	-	-	94
C (org)(gm)	16,275	30	10,880	-	1311	-
C(inorg)(gm)	6825[a]	690	-	-	10,959	-
Ca (gm)	12,930	13,270	-	-	-	103
Cd	106	-	-	0.18	-	-
Ce	6390	6060	-	0.090	-	95
Cl	-	-	-	-	-	-
Co	1350	1320	6.54	0.115	-	98
Cr	5470	12,175	4.91	0.16	-	223
Cs	688	641	-	0.025	-	93
Cu	5890	6685	55.8	461	-	172
Dy	364	345	-	-	-	95
Eu	92.9	90.7	0.001	0.001	-	98
Fe (gm)	3280	3040	1.10	0.054	-	93
Ga	1440	1330	0.11	0.043	-	92
H (gm)	2450[b]	60	1522	369	503	99
Hf	251	266	-	-	-	106
Hg (μg)	12,314	389	-	56	-	-
K (gm)	2490	2430	-	0.022	-	98
La	3050	3060	-	0.027	-	100
Lu	27.7	26.0	-	-	-	94
Mg (gm)	5030	5110	-	0.014	-	102
Mn (gm)	50.1	50.0	1.3	0.00058	-	102
Mo	3050	2915	2.2	-	-	95
N (gm)	821	20	193	-	-	
Na (gm)	2390	2260	0.00020	0.062	-	95
Nd	2785	2495	-	-	-	90
Ni	2990	4080	31.8	3.49	-	138
Pb	3460	6480	<22	<5.6	-	187
Rb	10,880	10,600	<9.3	0.106	-	97
S (gm)	484	529	126	-	-	-
Sb	327	309	0.039	3.66	-	96
Sc	949	882	-	-	-	93
Se	308	249	16.7	4.71	-	88
Si (gm)	22,580	21,100	1.4	-	-	93
Sm	452	433	-	-	-	96
Sr (gm)	100	96.0	<12	<3.3	-	96
Ta	68.9	105	-	-	-	152
Tb	58.6	56.9	-	-	-	97
Th	982	934	<18	<5.0	-	95
Ti (gm)	220	230	0.030	9.0	-	109
U	622	687	<31	0.030	-	110
V	15,250	12,800	3.1	0.76	-	84
W	205	269	-	0.063	-	131
Y	1950	2120	<14	3	-	109
Yb	199	191	-	-	-	96
Zn	9850	17,860	81.6	43.8	-	183

[a] Includes 38 gm of inorganic C in input gas

[b] Includes 29 gm of H in input steam

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Table 171

S-13 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure %
Al (gm)	4860	4770	0.01	-	-	98
As	4485	4775	256	7.56	-	112
Ba (gm)	59.9	-	-	-	-	-
C (org)(gm)	12,990	150	9451	51	1277	84
C(inor)(gm)	5720[a]	321	-	85.6	9182	150
Ca (gm)	10,610	11,100	-	-	-	105
Cd	87	-	-	-	-	-
Ce	5240	-	0.1	-	-	-
Cl	-	-	-	-	-	-
Co	1100	-	16.4	3.90	-	-
Cr	4485	-	4.68	1.48	-	-
Cs	564	-	-	-	-	-
Cu	4830	4575	191	< 19	-	95
Dy	298	-	-	-	-	-
Eu	76.2	-	0.0015	0.002	-	-
Fe (gm)	2690	2550	1.20	0.036	-	96
Ga	1180	1150	0.32	< 13	-	97
H (gm)	4342[b]	25	1310	2354	4.96	96
Hf	206	-	-	-	-	-
Hg (ug)	10,101	839	1799	<339	-	<29
K (gm)	2080	2110	-	0.12	-	101
La	2500	-	0.020	0.020	-	-
Lu	22.7	-	-	-	-	-
Mg (gm)	4120	4300	-	0.087	-	104
Mn (gm)	41.1	-	0.0029	0.000047	-	-
Mo	2300	-	24.9	-	-	-
N (gm)	613	-	227	-	-	-
Na (gm)	2250	1950	0.0026	0.55	-	87
Nd	2280	-	-	-	-	-
Ni	2450	3260	55.2	5.72	-	133
Pb	2840	3520	<25	-	-	124
Rb	8920	8810	<8.3	-	-	99
S (gm)	794	394	93	-	-	-
Sb	268	-	0.21	0.070	-	-
Sc	778	-	0.0024	-	-	-
Se	253	176	25.1	10.3	-	84
Si (gm)	18,520	17,710	0.95	-	-	96
Sm	370	-	-	0.001	-	-
Sr (gm)	83.9	80.3	< 14	< 21	-	96
Ta	56.5	-	-	0.12	-	-
Tb	48.1	-	-	-	-	-
Th	806	-	0.023	< 30	-	-
Ti (gm)	200	190	0.022	0.047	-	95
U	510	-	< 28	0.328	-	-
V	12,510	-	5.9	0.49	-	-
W	168	-	-	0.23	-	-
Y	1600	1840	< 12	< 23	-	115
Yb	164	-	-	0.030	-	-
Zn	8080	9900	58.8	< 15	-	123

[a] Includes 29 gm inorganic C in input gas.

[b] Includes 2332 gm H in input gas.

Table 172

S-14 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure %
Al (gm)	6035	5892	<0.0025	-	-	98
As	5570	6428	245	12.1	-	120
Ba (gm)	74.4	-	-	-	-	-
C (org)(gm)	16,430	124	10,260	-	1128	-
C(inor)(gm)	6976	258	-	-	10,580	-
Ca (gm)	13,175	13,800	-	-	-	105
Cd	108	-	-	0.71	-	-
Ce	6510	-	-	-	-	-
Cl	-	-	-	-	-	-
Co	1370	-	22.1	0.85	-	-
Cr	5570	-	6.42	8.65	-	-
Cs	700	-	-	-	-	-
Cu	6005	8240	193	<59	-	140
Dy	370	-	-	-	-	-
Eu	94.7	-	<0.002	<0.002	-	-
Fe (gm)	3346	3132	0.705	0.794	-	94
Ga	1465	1600	0.67	<37	-	109
H (gm)	5111[a]	44	1387	3137	646	102
Hf	255	-	-	-	-	-
Hg (μg)	12,547	103	4550	1244	-	47
K (gm)	2540	2554	-	-	-	101
La	3110	-	-	0.0076	-	-
Lu	28.2	-	-	-	-	-
Mg (gm)	5123	5490	-	<0.26	-	107
Mn (gm)	51.1	-	0.00292	0.029	-	-
Mo	3110	-	15.2	-	-	-
N (gm)	83.6	-	226	-	-	-
Na (gm)	2435	2586	0.0010	0.0865	-	106
Nd	2840	-	-	-	-	-
Ni	3047	5099	84.6	<71	-	170
Pb	3525	7695	56	<102	-	220
Rb (gm)	11.1	10.7	<8.5	<45	-	96
S (gm)	463	453	88	-	-	-
Sb	333	-	0.54	0.14	-	-
Sc	966	-	-	-	-	-
Se	314	216	33.5	13.1	-	84
Si (gm)	23,000	22,460	<1.1	-	-	98
Sm	460	-	-	-	-	-
Sr (gm)	101.9	99.4	<0.015	<0.57	-	98
Ta	70.2	-	-	-	-	-
Tb	60.0	-	-	-	-	-
Th	1000	-	<17	-	-	-
Ti (gm)	224	268	<0.007	<0.068	-	120
U	633	-	0.14	0.15	-	-
V	15,530	-	12	<0.8	-	-
W	210	-	-	0.16	-	-
Y	1987	2287	<12	<65	-	115
Yb	203	-	-	0.027	-	-
Zn	10,038	17,000	42.3	8.8	-	170

[a] Includes 2646 gm H in input steam

Table 173

S-15 mass balance (mg)

	Raw oil shale	Spent oil shale	Shale oil	Retort water	Gas	Closure (%)
Al (gm)	6170	5990	0.017	-	-	97
As	5700	5160	186	8.39	-	94
Ba (gm)	76.0	-	<6	-	-	-
C (org)(gm)	17,410	190	8500	83	1151	57
C(inor)(gm)	6429	240	-	158	10,920	176
Ca (gm)	13,470	13,060	-	-	-	97
Cd	110	-	-	-	-	-
Ce	6660	-	0.39	-	-	-
Cl	-	-	-	-	-	-
Co	1400	-	19.4	0.9[illegible]	-	-
Cr	5700	-	26.5	86.[illegible]	-	-
Cs	716	-	-	-	-	-
Cu	6140	8685	257	61.[illegible]	-	141
Dy	379	-	0.06	-	-	-
Eu	96.8	-	0.007	<0.002	-	-
Fe (gm)	3420	3470	0.830	0.100	-	101
Ga	1500	1430	1.0	<18	-	95
H (gm)	5546	42	1170	3280	850	96
Hf	261	-	-	-	-	-
Hg (ug)	12,827	105	3820	<502	-	<35
K (gm)	2600	2395	-	-	-	92
La	3180	-	0.161	0.0074	-	-
Lu	28.9	-	-	-	-	-
Mg (gm)	5240	5225	-	<0.012	-	100
Mn (gm)	52.2	-	0.017	0.0027	-	-
Mo	3190	-	10.2	0.30	-	-
N (gm)	550	6	173	-	-	-
Na (gm)	2490	2310	0.0343	0.[illegible]	-	93
Nd	2900	-	-	-	-	-
Ni	3115	8250	81.5	29.[illegible]	-	76
Pb	3600	15,150	43	<50	-	423
Rb	11,330	10,220	<7.1	0.36	-	90
S (gm)	672	481	74.5	-	-	-
Sb	341	-	0.92	0.[illegible]	-	-
Sc	938	-	0.023	-	-	-
Se	321	230	47.8	17.[illegible]	-	92
Si (gm)	23,515	22,885	<0.89	-	-	97
Sm	470	-	0.035	-	-	-
Sr	104.1	100.1	<12	-	-	96
Ta	71.8	-	-	-	-	-
Tb	61.1	-	-	-	-	-
Th	1020	-	0.11	-	-	-
Ti (gm)	229	240	<0.017	<0.036	-	105
U	647	-	1.22	0.033	-	-
V	15,880	-	21.4	<0.[illegible]	-	-
W	210	-	-	0.21	-	-
Y	2031	2415	<10	20	-	119
Yb	208	-	0.03	0.030	-	-
Zn	10,261	36,890	69.4	1[illegible].3	-	360

[a] Includes 3056 gm H in input steam

Table 174

L-1 mass balance (gm)

	Raw oil shale	Spent oil shale	Shale oil (dry)	Retort water	Gas	
Al (kg)	266	243	-	-	-	-
As	246	257	4.06	0.16	-	106
Ba	3280	3230	-	-	-	98
C (org)(kg)	711	-	403	0.38	44.8	-
C(inor)(kg)	311	-	-	233	555	-
Ca (kg)	580	617	-	<3.0	-	106
Cd	4738	-	-	-	-	-
Ce	287	263	-	0.001	-	92
Cl	-	-	-	-	-	-
Co	60.4	55.6	-	0.040	-	92
Cr	245	332	-	0.081	-	136
Cs	30.9	28.9	-	-	-	94
Cu	265	253	1.72	<0.19	-	96
Dy	16.3	14.9	-	-	-	91
Eu	4.17	3.86	-	-	-	93
Fe (kg)	147	134	0.025	0.00032	-	91
Ga	64	54	-	<0.1	-	84
H	110	-	55.6	20.9	22.6	-
Hf	11.2	11.7	-	0.0004	-	104
Hg (mg)	553	4.3	41.7	3.6	-	9
K (kg)	112	101	-	0.0034	-	90
La	137	134	-	0.0026	-	98
Lu	1.24	1.20	-	-	-	97
Mg (kg)	226	232	-	0.0013	-	103
Mn	2250	2114	<1.1	0.032	-	94
Mo	137	132	-	0.024	-	96
N	33.6	-	9.2	-	-	-
Na (kg)	107	104	-	0.034	-	97
Nd	125	110	-	-	-	88
Ni	134	143	1.91	<0.06	-	108
Pb	155	267	0.63	<0.32	-	173
Rb	488	431	<0.34	<0.0034	-	88
S	43.4	-	3.9	-	-	-
Sb	14.7	13.6	-	0.015	-	-
Sc	42.6	37.3	-	-	-	88
Se	13.8	9.5	0.52	0.043	-	73
Si (kg)	1013	923	-	-	-	91
Sm	20.3	18.6	-	-	-	92
Sr	4488	4400	-	0.051	-	98
Ta	3.1	15.1	-	-	-	487
Tb	2.6	2.4	-	-	-	92
Th	44.1	42.5	-	<0.28	-	96
Ti (kg)	9.9	9.1	-	<0.00066	-	92
U	27.9	31.0	-	0.037	-	111
V	684	656	-	0.030	-	96
W	9.2	11	-	0.024	-	120
Y	87.5	95.3	-	<0.21	-	109
Yb	8.95	8.58	-	-	-	96
Zn	442	746	2.05	0.11	-	169

Table 175

TABLE 176. RETORT WATER PRODUCED BY SOME SURFACE AND IN SITU PROCESSES

Process	Ratio of Water to Oil (Volume Basis)
In Situ Retorts:	
True in situ Rock Springs Site 9	22.2
MIS with steam Occidental Retort #5	11.5
Simulated in situ with steam LLL 125 KG Retort	2.30
True in situ rock springs site #7	0.66
Horizontal in situ geokinetics retort #11	0.68
True in situ rock springs site #4	0.40
Simulated in situ with N_2 LLL 125-KG retort	0.40
Surface Retorts:	
Fisher Assay	0.15
Paraho direct	0.17
Paraho indirect	0.08
Tosco II	0.30

APPENDIX I

CORE HOLE SUMMARY--CORE HOLE C-A-2 -

1. LOCATION: SE NW NE, sec. 32, T.1 S., R.99 W.
Rio Blanco County, Colorado

2. ELEVATION: 6993' Gl, 7000 KB

3. OPERATOR: The Oil Shale Corporation (TOSCO)

4. CONTRACTOR: Dreiling Drilling Company, Denver, Colorado
Rig #4, Tool Pusher -- Ralph Dreiling

5. GEOLOGISTS: J. L. Moyer, A. M. Blackford, E. C. Mast;
Amuedo and Ivey, Denver, Colorado

6. SPUD DATE: 26 October 1973

7. DRILLING FLUID: Gel Mud 0- 173'
Air Mist 173-1130'

8. BIT RECORD:

No.	Size	Type	Serial	From	To	Footage
1	8 3/4"	HTC OSC 3A	Rerun	0'	173'	173'
2	6 1/4"	HTC OSC 3	MN 747	173'	180'	7'
3	6 1/4x3 1/2"	Chris MC20	354436	180'	1130'	950'

9. CASING: 7" at 155.6' (164' Logger), cemented to surface.

10. LOGS:

Sample and core:	Surface to 1130'
Dual Induction Laterolog:	164' to 1126'
Formation Density:	164' to 1129'
Temperature:	Surface to 1130'
Flow meter:	230' to 1130'

11. FORMATION TOPS AND MARKERS:

	Depth	Sea Level Datum
Base "A" Groove	210'	+6790
Mahogany Marker	231'	+6759
Top "B" Groove	334'	+6666
Top Garden Gulch	1096'	+5904

12. TOTAL DEPTH: 1130'

13. COMPLETION DATE: 5 November 1973

Prepared by Amuedo and Ivy
Preceded by location map, 1,24,000

APPENDIX I.1

DAILY LOG--CORE HOLE C-A-2

25 Oct. 1973 - Rigging Dreiling Drilling Company Rig #4.

26 Oct. - Drill rat hole. Spud surface hole 1030 h, drill to 173' at 1645 h. Set 155.6' (Logger 164'), 7" 20# surface casing. Cement to surface, W.O.C. at 2400 h.

27 Oct. W.O.C. set B.O.P. and flowlines to 1600 h. Drill cement, plug, and 7 feet formation. Trip for core barrel, cut core #1, out of hole, depth 197' at 2400 h.

28 Oct. Cut and recover cores 2 and 3. Noticed surface pipe loose at 1030 h. Wait on cementers to 1900 h. Cement surface pipe, top job. W.O.C., depth 250' at 2400 h.

29 Oct. W.O.C. to 0700 h. Cut and recover cores 4 and 5, cutting core #6, 359' at 2400 h.

30 Oct. Cut and recover cores 6 through 9, cutting core #10, 511' at 2400 h.

31 Oct. Cut and recover cores 10 through 13, cutting core #14, 704' at 2400 h.

1 Nov. Cut and recover cores 14 and 15, 1400 h. Ran jet pumping test at 781' depth to 1800 h. Cutting core #16, 828' at 2400 h.

2 Nov. Cut and recover cores 16 through 18. Cutting core #19, 943' at 2400 h.

3 Nov. Cut and recover cores 19 through 21. Cutting core #22, 1110' at 2400 h.

4 Nov. Cut core #22 to 1130' T.D. at 0200 h. Circulate for logs 30 minutes, trip out core #22 at 0400 h. Wait on logger 0730 h. Rig up and logging 0900 h, could not go to bottom. Trip in hole reaming to clear bridges, out of hole and logging at 1300 h. Finish logging and rig down at 2000 h. Trip in open-ended for jet pumping test. Testing at 1130' T.D. at 2400 h.

5 Nov Complete water test at 0030 h. Trip out laying down pipe and rigging down. Shut down at 1600 h.

APPENDIX I.2

CORE RECORD--CORE HOLE C-A-2

RUN	FROM	TO	CUT	RECOVERED	% RECOVERY
1	180.0	197.2	17.2	16.6	96.5
2	197.2	237.2	40.0	37.1	92.7
3	237.2	250.0	12.8	10.5	82.0
4	250.0	310.9	60.9	59.0	96.9
5	310.9	345.2	34.3	33.7	98.3
6	345.2	362.7	17.5	17.5	100.0
7	362.7	403.2	40.5	32.8	81.0
8	403.2	438.8	35.6	32.5	91.3
9	438.8	465.5	26.7	22.4	83.9
10	465.5	520.0	54.5	53.2	97.6
11	520.0	578.7	58.7	55.9	95.2
12	578.7	634.0	55.3	52.7	95.3
13	634.0	684.7	50.7	48.2	95.1
14	684.7	736.2	51.5	49.0	95.1
15	736.2	781.7	45.5	44.5	97.8
16	781.7	842.0	60.3	56.5	93.7
17	842.0	880.0	38.0	35.2	92.6
18	880.0	937.8	57.8	55.0	95.2
19	937.8	967.9	30.1	25.0	83.1
20	967.9	1031.5	63.6	59.7	93.9
21	1031.5	1091.3	59.8	59.8	100.0
22	1091.3	1130.0	38.7	38.7	100.0
Total			950.0	895.5	
			Overall recovery		94.3%

APPENDIX I.3

STRUCTURE AND PHYSICAL PROPERTIES OF THE ROCK

MARKERS AND ZONES CORE HOLE C-A-2

The following lithologic markers and zones were identified in the C-A-2 on the basis of sample observation, logs, and assays:

MARKER OR ZONE	Sample		Log		Assay	
	Depth	Datum	Depth	Datum	Depth	Datum
Alluvium	Surface	+6993	KB	+7000	---	---
Bedrock	----	---	103'	+6897	---	---
Top Parachute Creek	103'	+6897	---	---	---	---
Top "A" Groove	193.6'	+6806	194'	+6806	193'	+6807
Top Mahogany Zone	208'	+6792	210'	+6790	206'	+6794
Mahogany Marker	231'	+6769	---	---	---	---
Top "B" Groove	336'	+6664	334'	+6666	336'	+6664
Base "B" Groove	352'	+6648	351'	+6649	352'	+6648
Top Barren Zone	491'	+6509	490'	+6510	Not assayed	
Base Barren Zone	630'	+6370	592'	+6408	"	"
Top Garden Gulch	1095'	+5905	1096'	+5904	"	"

Bedrock, estimated at 103 feet, is an erosional surface probably below the true top of the Parachute Creek Member.

Rock Quality Designation (RQD)

Rock Quality Designation (Deere, 1969) is a quantitative evaluation of the rock determined by examining the core for natural breaks including partings, joints, fractures, and faults, and the general weathered condition of the rock. The information is quantified by summing the lengths of all pieces of unweathered core longer than 0.35 foot between natural breaks, and dividing by either run length (RQD-1) or a standard interval (RQD-2).

The values derived, expressed as a percentage, determine the rock classification according to the following grouping:

RQD	Rock Classification
0-25%	Very poor
26-50%	Poor
51-75%	Fair
76-90%	Good
91-100%	Excellent

Rock Quality

RQD-1, based on run lengths with a 60-foot core barrel, indicates that on an average the rock is of fair quality between 130 and 580 feet, and of mostly good quality from 580 feet to the top of the Garden Gulch Member at about 1090 feet.

RQD-2 was calculated using a standard 10-foot length to provide better definition of the variations in rock quality known to occur within the long core runs obtained. This classification shows that the rock is quite variable in quality. Throughout the cored interval generally thin zones of poor to very poor rock are interspersed between thicker units of fair- to good-and excellent-quality rock. Overall, only 22 percent of the rock is poor or very poor quality, whereas 47 percent is of good and excellent quality.

No information relative to mining sections or methods is available at the time this report is prepared. Therefore, no specific engineering or mining conclusions can be drawn.

Partings, Joints, and Fractures

Natural breaks logged consist of partings essentially parallel to the bedding, and fractures and joints crossing the bedding at various angles. Nahcolite cavities usually produced a "natural" break in the core. The overall rock quality should not be affected except possibly in concentrated zones of these cavities. Natural partings are spaced from less than one inch to one or two feet throughout much of the core and the intervals reach maximums of over 10 feet in sections of the core from the lower part of the Parachute Creek Member. Many partings showed calcareous, talc, or other mineral coatings, and nearly all joints and fractures, open or sealed, had coatings, crystal fillings, or were slickensided with smoothed surfaces. However, the rock itself is predominantly sound and unweathered.

For measuring the dip of bedding and the inclination of joints and fractures the axis of the core was assumed to be vertical, and values shown represent angles from a plane through the core normal to the axis.

The bedding is predominantly horizontal with some portions of the core showing dips as steep as 30°. The steepest dips are usually in short intervals and probably reflect only irregularities associated with nearby nahcolite cavities. Joints and fractures have dips as shallow as 15°, and up to vertical. No strong concentrations of joint dip values were observed, although 65 percent were between 70° and vertical. Slight groupings are present at 50° and 60°, and lower values are more or less uniformly represented.

The spacing between joints and fractures varies irregularly from less than one inch to over 10 feet in the upper part of the section. Below a depth of about 805 feet these breaks are mostly very widely spaced with only a few short intervals of closer spacing.

Hydrology

The surface hole through about 100 feet of alluvium and 80 feet of bedrock was drilled with mud and no water flow data could be obtained. Below surface casing measured flow volumes were less than the amount of water injected. The first water flow was noted at a depth of about 339 feet in "B" groove. This flow was accompanied by a strong hydrogen sulfide odor which disappeared within a few hours. Observed water quantities varied between 13.5 and 23.3 gallons per minute (gpm) to a depth of 450'.

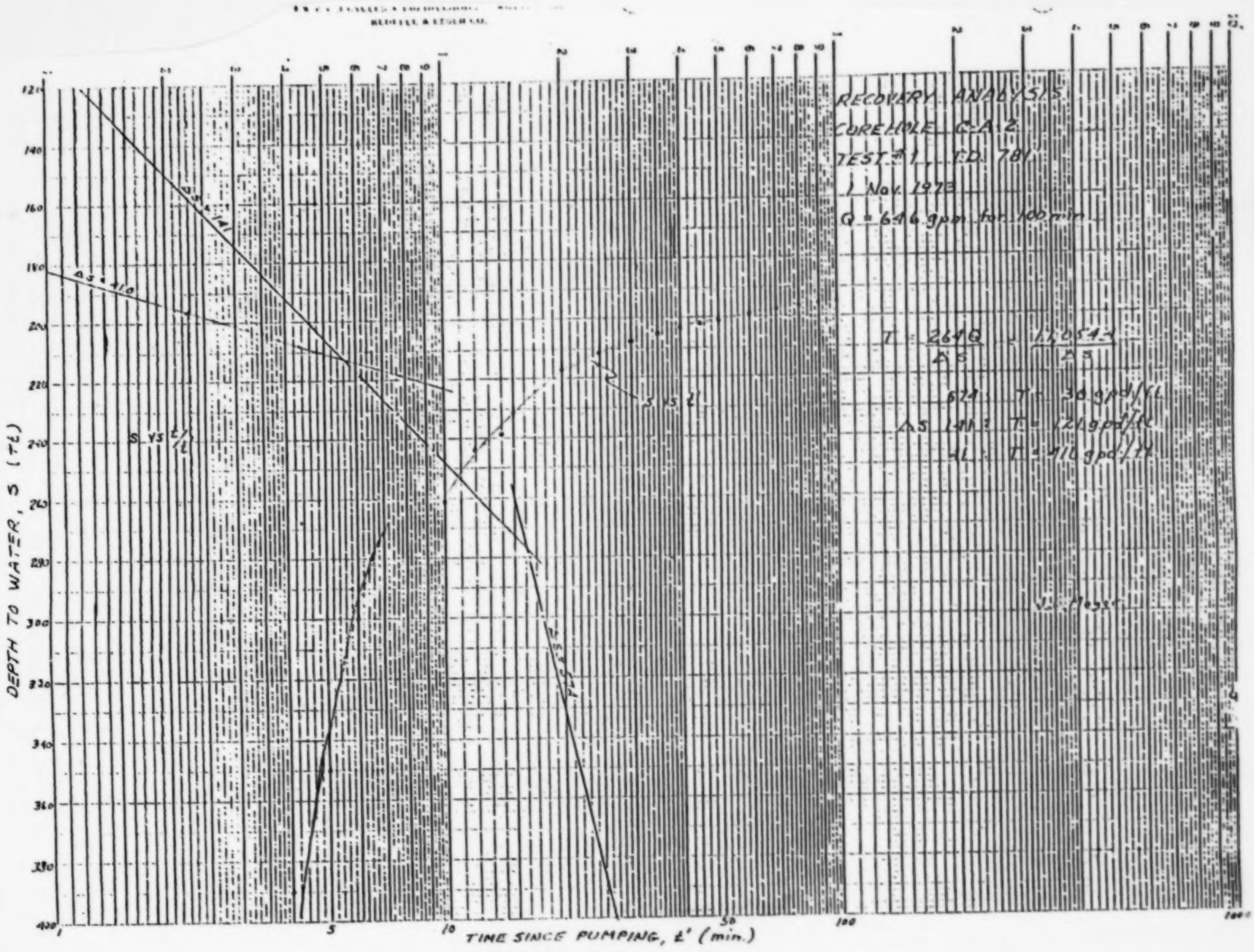
Below that depth a gradual small increase was noted and quantities had reached about 50 gpm at 700 feet. The maximum volume of 155 gpm was recorded while drilling at 1091 feet.

Two jet pumping tests were made; the first after water had reached a moderate volume at 781 feet, and the second at total depth in the Garden Gulch Member. Figures 2 and 3 are plots of recovery versus time for each test. In both tests apparent discontinuities in recovery rate are noted which affect the calculated transmissivity (T). Of three possible values for T calculated in test #1, the value 141 gallons per day per foot (gpd/ft), from the central part of the curve, is probably most nearly correct. Either value computed from the two slopes in test #2 may be as valid as the other, therefore the average value, 1024 gpd/ft, was computed.

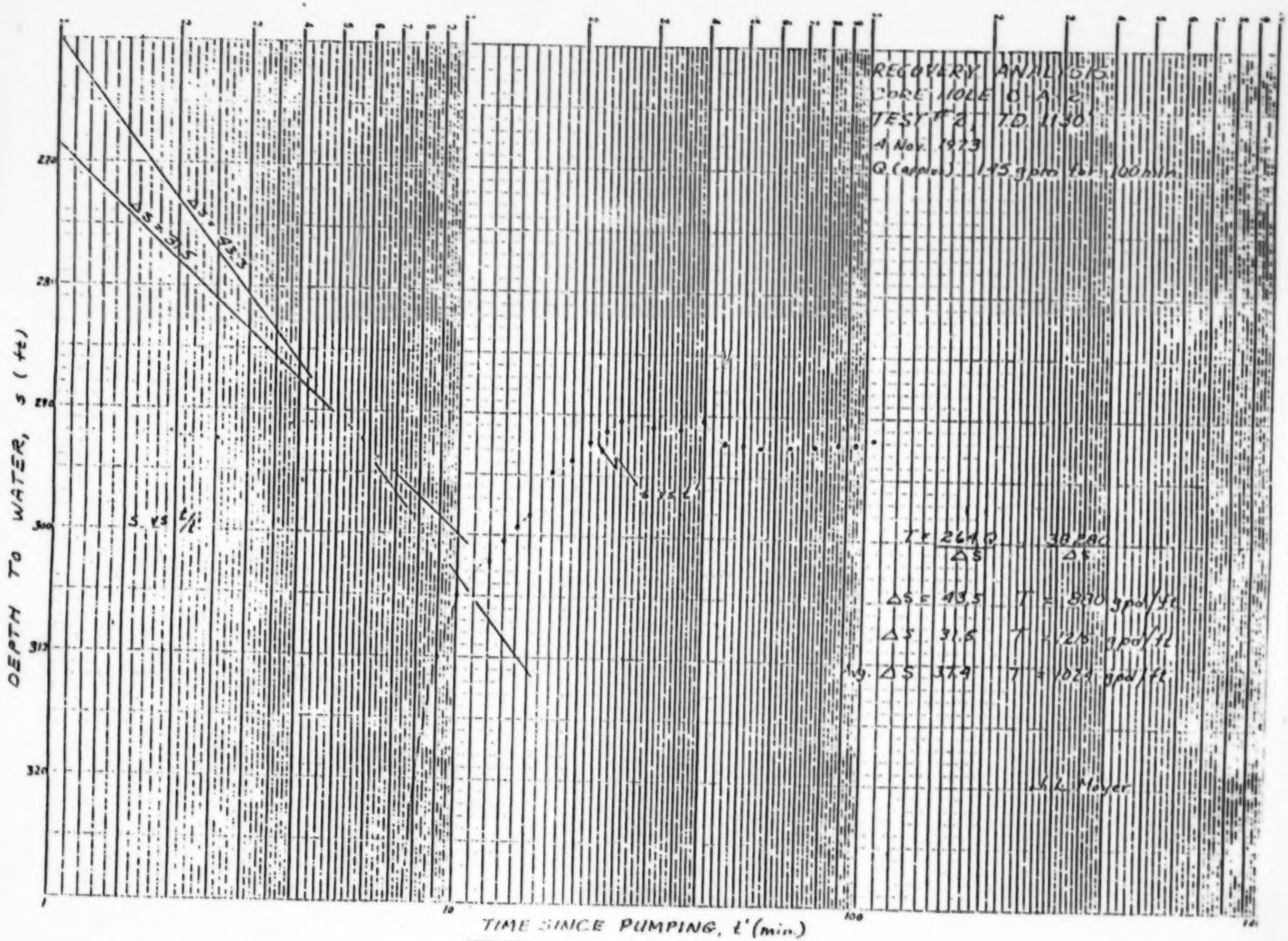
Maximum recorded water temperature during drilling and testing was 12.5°C. (54.5°F.). Maximum in-hole temperature recorded on the temperature survey was about 68°F. at the bottom of the hole. Measured conductance ranged between 1250 and 1850 micromhos per centimeter; equivalent to about 850 to 1400 parts per million dissolved solids.

REFERENCE

1. Deere, D. U., Merritt, A. H., Coon, R. F., 1969, Engineering classification of in-situ rock: AFWL-TR-67-144, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico.



APPENDIX I Figure 1



APPENDIX I Figure 2

APPENDIX II

COMPLETION REPORT

Dreiling Drilling Company of Denver, Colorado, rigged up on location CH-6 (SE, SE, Sec. 34 T1S, R99W) on July 3, 1974. Drilling commenced and 160 feet of surface casing was set on that date. Coring began on July 4, 1974 with significant water production encountered at a depth of 180± feet, at which time hydrologic data collection commenced.

Hydrologic data were collected in two basic categories: water production and water quality. Water production was monitored throughout drilling by means of a Parshall flume installed as the outlet in the blooey pit. The water levels in the flume were measured by an automatic recording float device, a Stevens Type F unit.

Water quality was tested at approximately thirty-foot intervals by measuring conductivity, pH and temperature. In addition, a set of samples was collected at each of four intervals during drilling: 1) at first significant production, 2) end of the "B groove" pump test, 3) increase in production after "B groove", and 4) at total depth. These samples were analyzed by The Industrial Laboratories Company of Denver through both standard wet chemical and spectrographic methods.

To evaluate the potential of the aquifer systems, informal pump tests were conducted twice during drilling: after the "B" groove had been penetrated and after reaching total depth. These consisted of two hours of continuous airlift pumpage (during the coring process), discontinuing the pumping, and the recording of water level increases by a downhole pressure recorder set inside the drillstring (See Figures 3 and 4).

The corehole was completed by landing and cementing casing, after Schlumberger Well Service Company ran a suite of geophysical logs on July 23, 1974.

WATER PRODUCTION

Water production was monitored continuously by utilizing a Parshall flume and stilling well adapted with a Stevens Type F recorder. These are mounted as the outlet for the blooey pit at each site. As production (by virtue of the air-mist injection during drilling) increases and decreases, the water level fluctuations in the stilling well raise and lower a float device attached to the recording drum and pen. Converting the recordings (in tenth of a foot) to gallons per minute thus enables one to plot and evaluate the production versus depth for the well. Figure 1 attached shows water production and temperature versus depth.

Water production on CH-6 remained negligible until a depth of 180± feet was reached, at which time the well produced 22± gallons per minute (gpm). Production increased steadily to 375 gpm at 685± feet, with three minor decreases noted at 360 - 380 feet, 500 - 520 feet, and 640 - 680 feet. A general decrease in production was then encountered from 375 gpm to 245± gpm at 1055 feet A sharp decrease at 1060 feet (to 180 gpm), an increase to 285 gpm at 1150 feet,

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and additional loss to 168± gpm at 1320 feet followed. Between 1320 feet and 1460 feet, production increased rapidly to 550± gpm. This increase was due to the penetration of the lower aquifer. From 1460 feet to total depth, production varied from 475 gpm to a maximum of 570 gpm at 1695 feet.

WATER QUALITY

Water quality was monitored throughout the drilling. At approximately thrity-foot intervals a sample was tested for temperature, pH, and conductivity. In addition, samples were collected at 200-foot intervals and tested for dissolved oxygen content and chlorine content. Samples were also collected at four intervals, and sent to The Industrial Laboratories Company of Denver, for complete analysis: 1) at first significant production, 2) during "B groove" pump test, 3) significant increase below "B groove", and 4) at total depth. Table I below summarizes the thirty-foot water quality measurements.

Temperature and pH. Figure 1 shows the temperature variations of the water produced during drilling. These ranged from a low of 57°F to a high of 81°F.

Upper aquifer temperatures ranged from 57° - 66°F to a depth of 1300± feet. Combined aquifer water averaged 75°F below 1300 feet, with a distinct increase at the top of the lower aquifer (1310± feet).

The pH records show a high reading of 8.5 and a low of 6.8. The pH record is shown on Figure 2 attached.

Conductivity. Corrected conductivity readings, (see Figure 2) give values ranging from a low of 978 μmhos/cm to a high of 4000 umhos/cm The upper aquifer averaged approximately 1200 μmhos/cm to 630 feet. The combined aquifer averaged approximately 2840 μmhos/cm from 1300 feet to total depth.

TABLE I

WATER QUALITY CH-6

	Upper Aquifer (180' - 630')	Lower Aquifer (1300' - 1780')
Conductivity (μmhos/cm @ 25°C)		
High	1500	4000
Average	1200±	2840
Low	978	1050
Temperature (°F.)		
High	66	81
Average	62	75
Low	57	62
pH		
High	8.5	8.5
Average	7.6	7.9
Low	6.8	7.6

The Industrial Laboratories Company analyzed the water samples which were collected, and submitted detailed qualitative results. Copies are not included herein, but are available if a review is necessary.

INFORMAL PUMP TESTS

Two informal pump tests were conducted during drilling. The first was run after penetration of the "B groove" at a depth of 767 feet. The second was conducted at total depth. Each pump test consisted of two hours of continuous airlift pumpage, after which a downhole pressure recorder was lowered inside the drillstring. This instrument records the rising water level as pressure, which can then be converted to feet of recovery. Figures 3 and 4 are the results of these two recovery tests. From these, the calculations of the approximate transmissivity, static water level, and specific capacity can be made for the upper and combined aquifers.

Table 2 below summarizes the results of the pressure bomb tests:

TABLE 2
INFORMAL PUMP TESTS
CH-6

	Upper Aquifer	Combined Aquifers
Production	300± gal. per min.	530± gal. per min.
Static Water Level	40± feet	< 200 feet
Transmissivity	175 - 19,800 gpd/ft	365± gpd/ft
Specific Capacity	.50 gpm/ft of drawdown	0.24 gpm/ft of drawdown

The first recovery test provides realistic estimates for all three aquifer characteristics. The initial rapid increase of the water level to near static water level is somewhat influenced by a "pressuring up" of the aquifer, therefore creating an abnormally high recovery rate. It also is rather anomalous in that the sharp break in slope indicates that a boundary effect is present in the vicinity of the well, adding to the rapid recovery. The second calculation of transmissivity (T_2 = 19,800 gpd/ft) therefore, is a more accurate indication of upper aquifer potential. The specific capacity (S.C. =0.50 gpm/ft) correlates with production and is also a realistic estimate.

The second recovery test yields an anomalously low transmissivity. The recorder had a maximum of 500 psi capability, which was overcome by the total head of recovery at about 90 minutes after shutdown.

The plot of recovery data, therefore, does not realistically represent the combined aquifer potential. The transmissivity of the combined aquifer should be near the same magnitude as that for the upper aquifer alone. The specific capacity is a reliable figure for the combined aquifers.

PRODUCTION LOGGING

Schlumberger Well Service Company ran two specialized logs for purposes of evaluating water movement and water temperature in the borehole. The Temperature Log data are plotted on Figure 5. The Engineered Production Log, which measures the velocity of nonpumping water in the borehole, is also plotted on Figure 5. The value of this curve, although taken directly from the log data, is to show relative water movement downhole rather than absolute velocities as indicated by the specific values shown on the horizontal axis.

Interpretation of the Production Log is shown in Figure 6. This plot details zones of water entry, water loss and cumulative downhole water movement. These plots are highly interpretive and are subject to some quantitative arbitration. It does define, however, major zones of water entry and loss. Major production from the upper aquifer is between 260 and 630 feet, producing up to 500± gpm downhole. The lower aquifer lies between 1465 to 1480 feet and 1550 to 1580 feet (Figure 6).

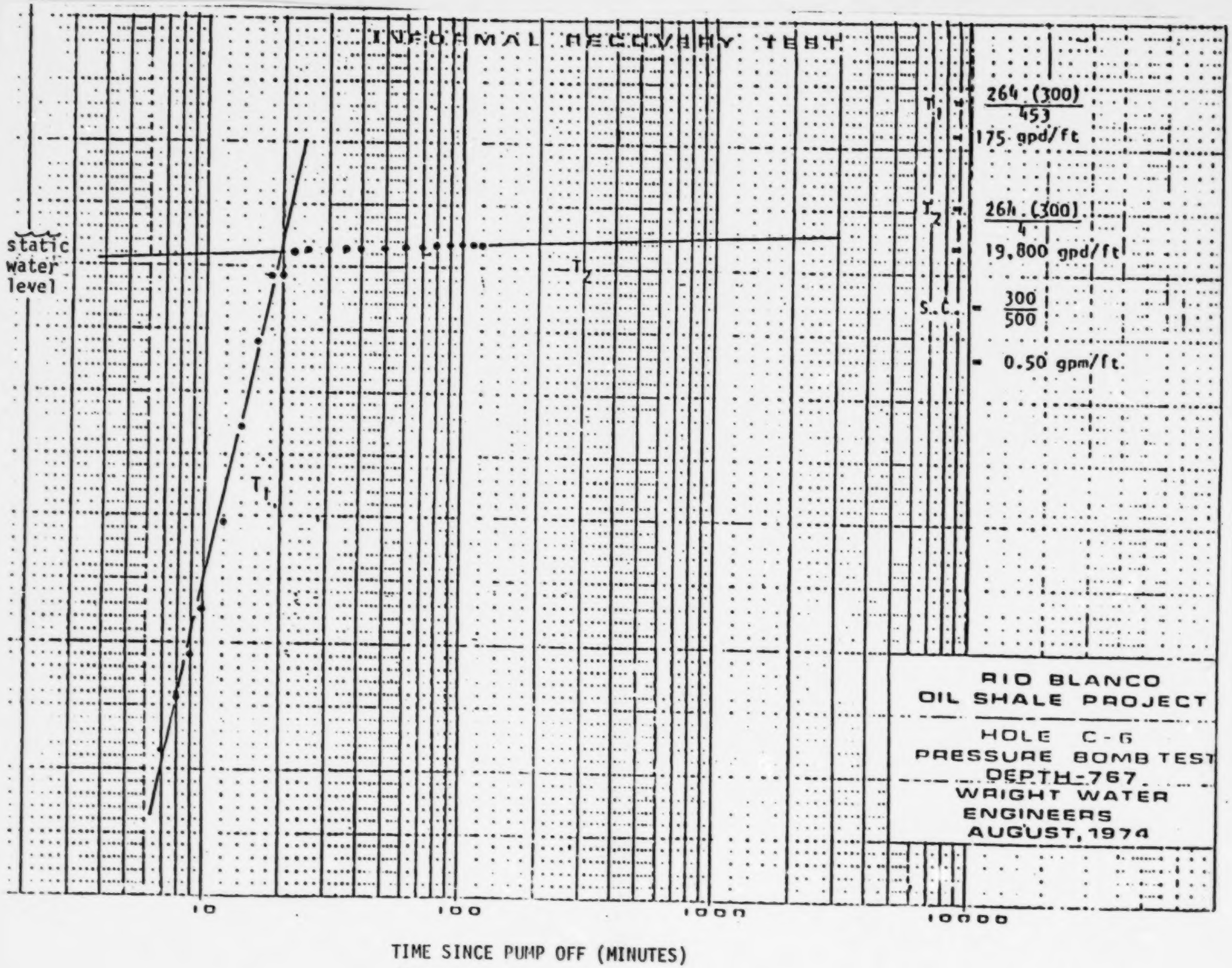
The static water level for the upper aquifer is approximately 40± feet. The static water level for the combined aquifers is approximately 150-200 feet. The differential in head (pressure) between the two aquifers results in the net downhole recharge into the lower aquifer.

The zones of loss and production in the lower aquifer (1465 to 1580 feet) are interpretive. Theoretically, these zones cannot exist under these highly differing pressure conditions. However, these losses and gains do appear to exist on the Production Log and are therefore presented as such. Further pump tests and evaluation may provide additional data with which a better interpretation can be formulated.

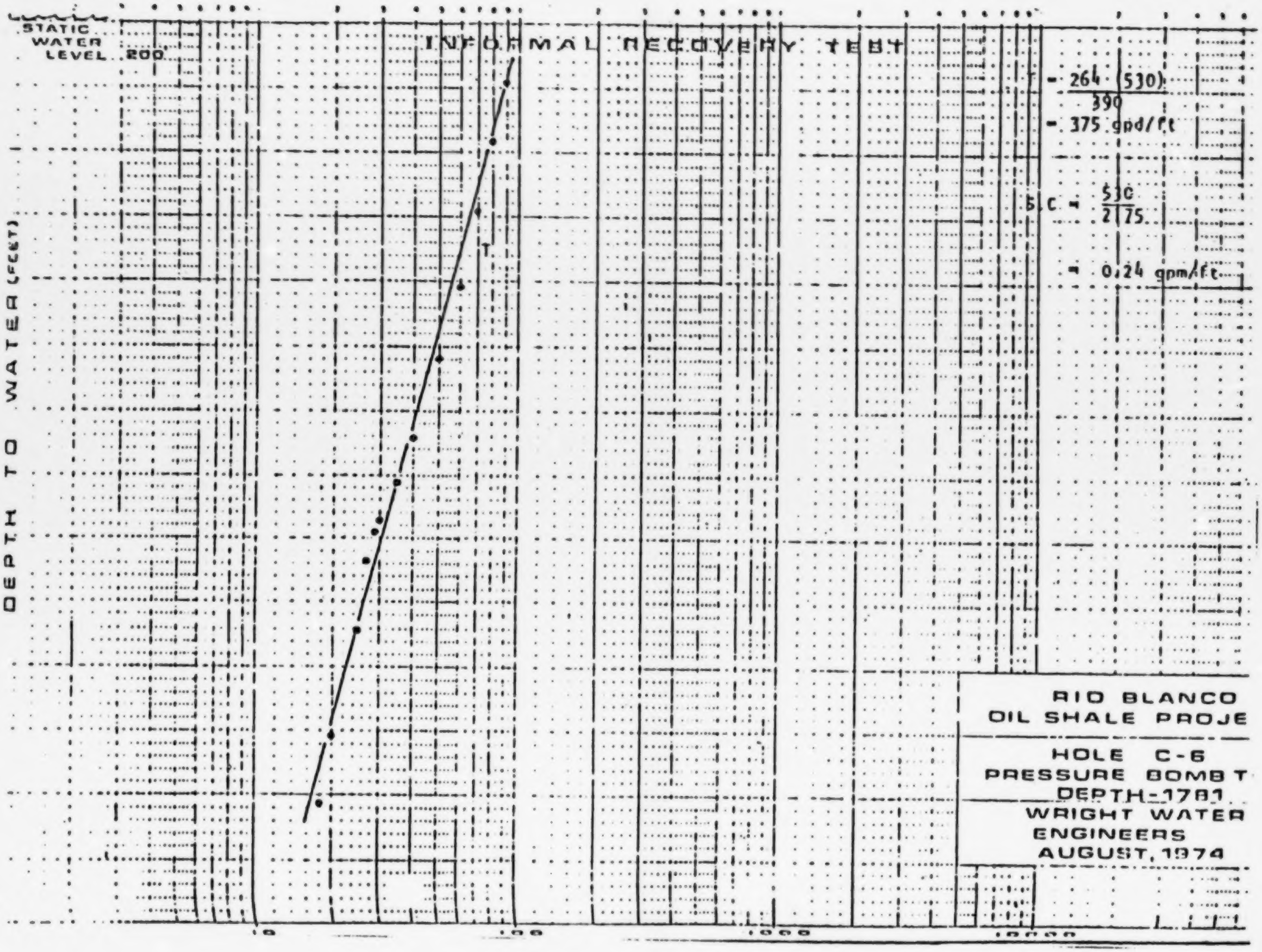
SUMMARY AND CONCLUSIONS

Core Hole 6 was completed on July 23, 1974. Preliminary analysis of the data obtained during drilling and informal pump tests yields the following list of conclusions which appear to be valid for the hydrology of CH-6.

1.	Static Water Levels	
	Upper Aquifer	40± (G.L.)
	Combined Aquifer	200±
2.	Maximum Production	
	Upper Aquifer	375± gpm
	Combined Aquifer	575± gpm
3.	Transmissivity	
	Upper Aquifer	175 - 19,800 gpd/ft
	Combined Aquifer	365± gpd/ft

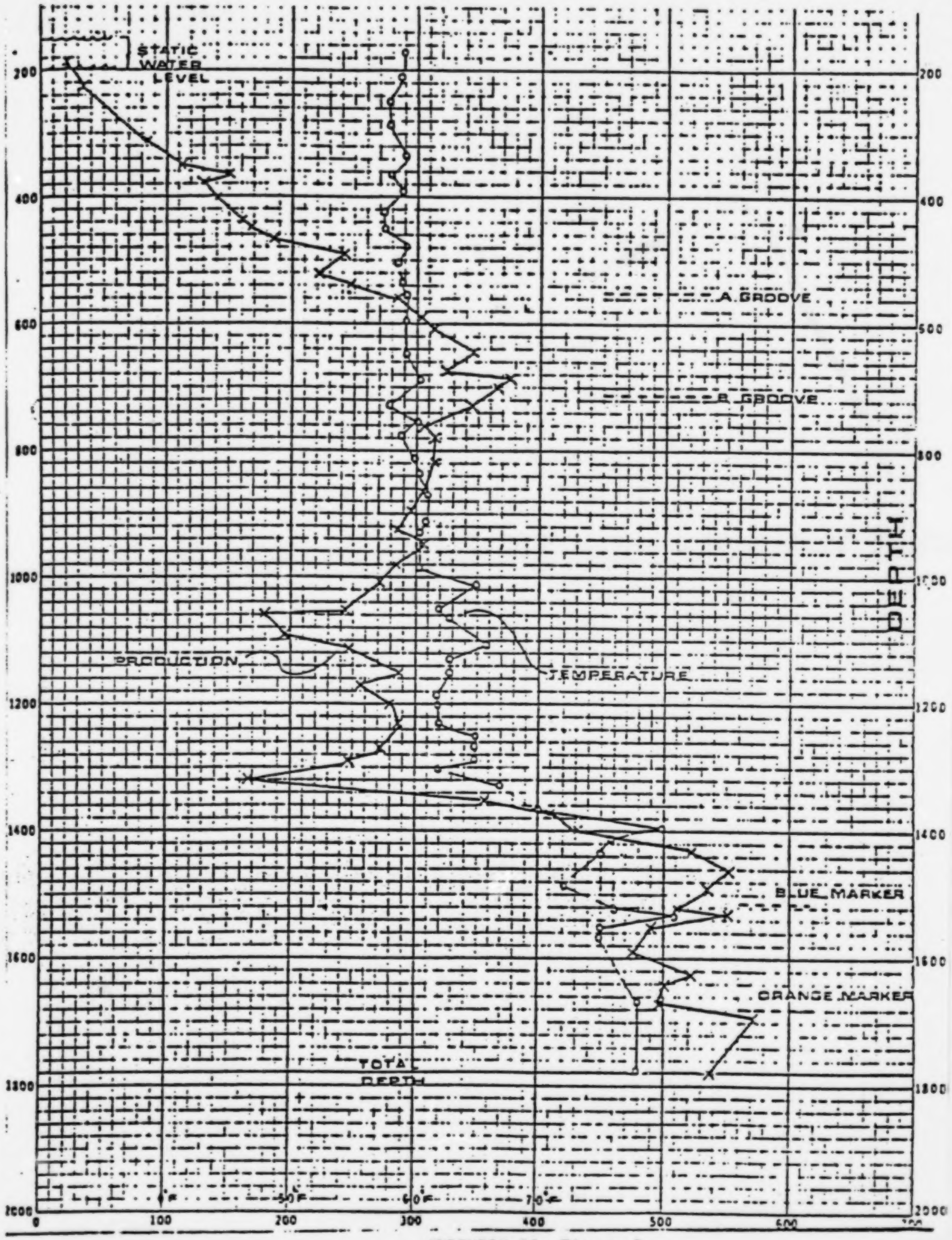


APPENDIX II Figure 1

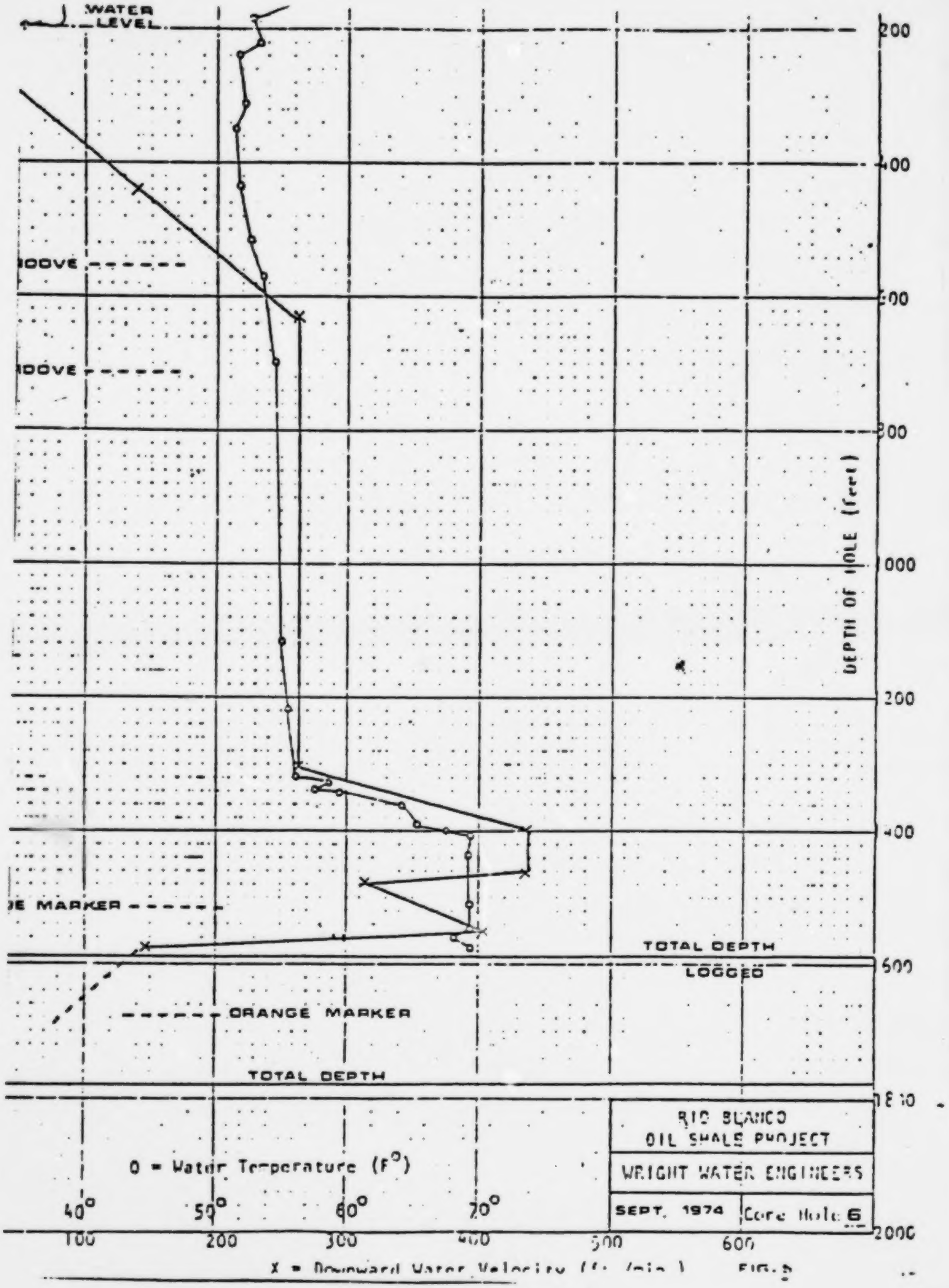


APPENDIX II Figure 2

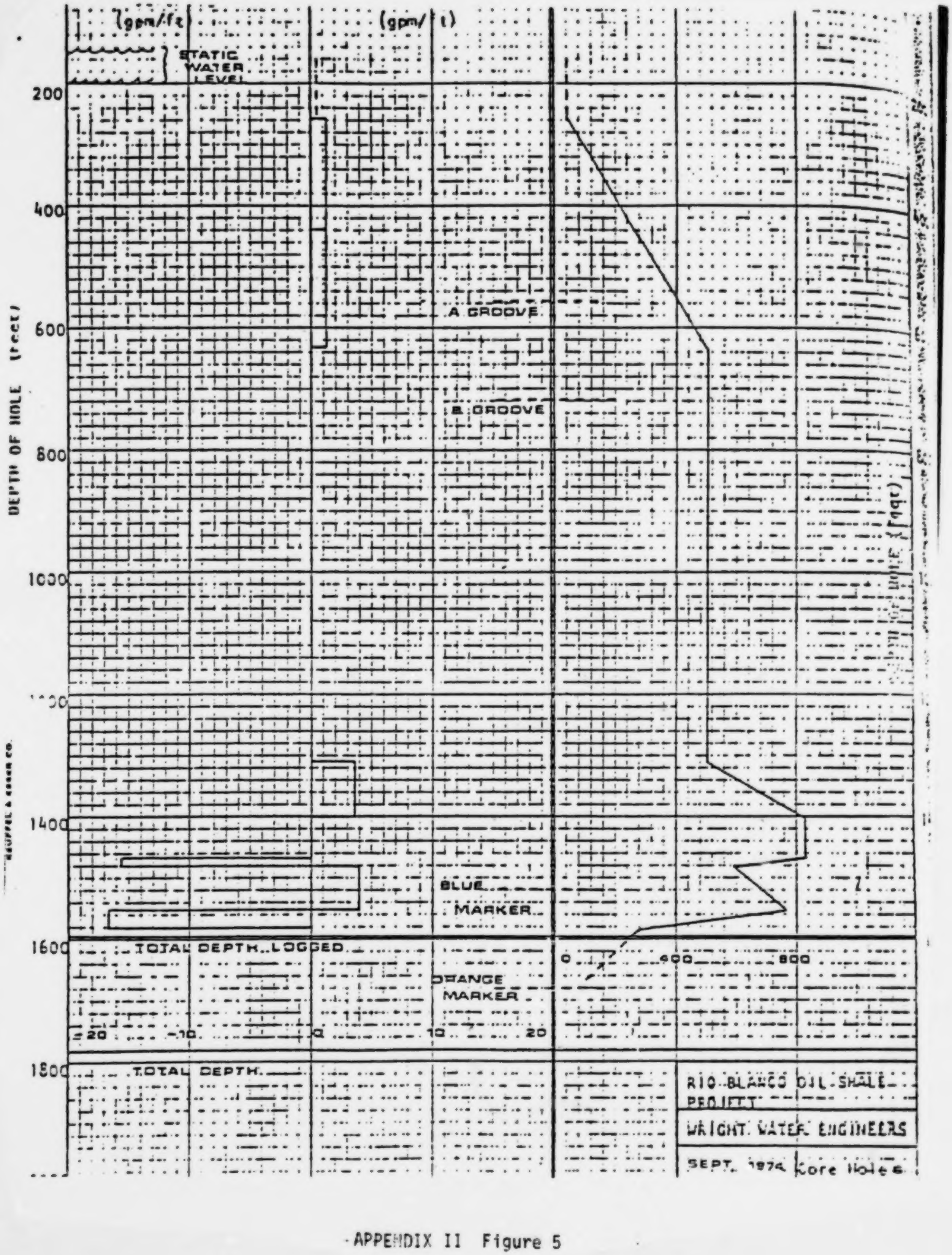
WATER PRODUCTION AND TEMPERATURE
vs. DEPTH



APPENDIX II Figure 3



APPENDIX II Figure 4



APPENDIX II Figure 5

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APPENDIX III

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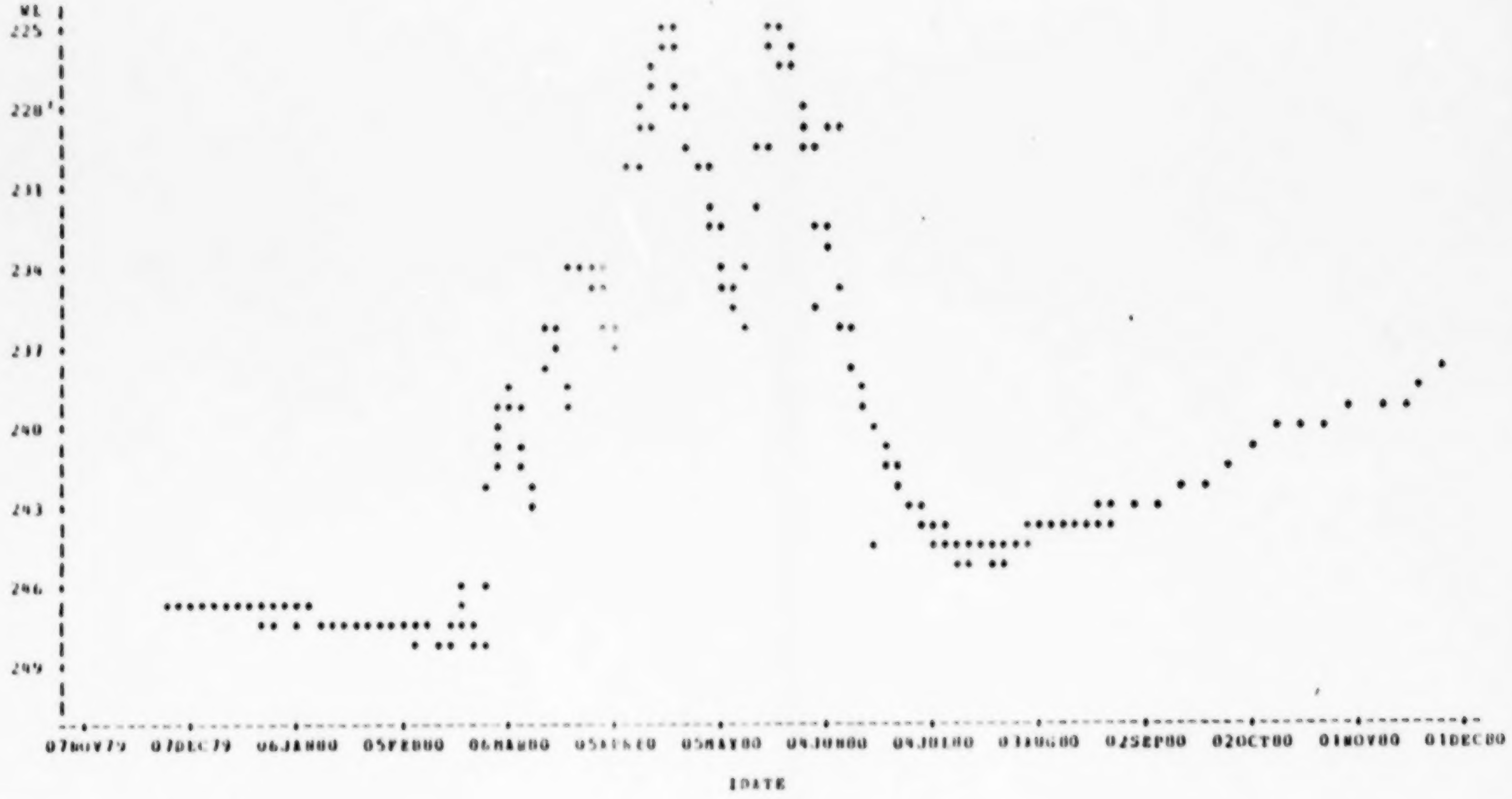
RIO BLANCO HYDROLOGY MONITORING PROGRAM
1980 REPORT YEAR
GROUND WATER PHYSICAL DATA

STA	MO	DAY	YR	WL	TEMP	COND	pH
AM-2AU	1	30	80	375.00	10.3	1450	7.8
AM-2AU	2	6	80	375.00	10.3	*	*
AM-3U	1	30	80	32.70	11.8	1100	8.2
AM-3U	5	13	80	31.40	10.5	1100	8.3
CE-701U	12	26	79	152.60	11.6	1180	*
CE-701U	1	30	80	154.50	11.9	1205	7.3
CE-701U	2	25	80	155.30	12.2	1300	7.6
CE-701U	3	17	80	156.60	11.0	1200	7.9
CE-701U	4	24	80	158.40	13.0	1350	8.5
CE-701U	5	7	80	158.70	13.0	1200	7.4
CE-702U	12	27	79	50.00	12.8	1420	8.2
CE-702U	1	30	80	49.40	12.3	1350	7.9
CE-702U	2	25	80	45.50	13.2	1300	7.9
CE-702U	3	17	80	43.00	12.2	1250	8.3
CE-702U	4	23	80	44.40	14.8	1350	8.3
CE-702U	5	5	80	42.50	14.5	1400	7.9
CE-705AU	12	26	79	244.20	11.1	1100	*
CE-705AU	1	29	80	244.50	11.4	1150	7.5
CE-705AU	2	25	80	246.60	11.0	1200	7.5
CE-705AU	3	19	80	247.20	11.0	910	7.8
CE-705AU	4	23	80	250.05	12.0	1050	8.5
CE-705AU	5	13	80	257.00	11.0	1250	7.8
CE-707U	12	26	79	247.00	10.3	1250	*
CE-707U	1	30	80	247.80	10.9	1350	7.5
CE-707U	3	17	80	236.20	9.0	1650	8.0
CE-707U	4	24	80	228.00	11.0	1500	8.2
CE-707U	5	14	80	232.10	10.0	1425	7.3
CE-709U	12	27	79	242.50	9.2	1700	7.4
CE-709U	1	30	80	244.60	9.4	1650	7.0
CE-709U	2	26	80	245.50	11.2	1700	7.6
CE-709U	3	17	80	244.80	10.8	1500	7.6
CE-709U	4	23	80	245.80	11.8	1675	8.0
CE-709U	5	14	80	247.20	10.0	1700	7.4
GS-M1U	12	19	79	655.80	13.5	1250	8.3
GS-M1U	1	30	80	655.80	15.6	1275	7.5
GS-M1U	2	26	80	654.90	13.8	1375	7.2
GS-M1U	3	17	80	651.30	11.8	1400	8.5
GS-M1U	4	23	80	651.30	14.6	1375	8.1
GS-M1U	5	7	80	650.80	14.6	1300	7.9

RIO BLANCO HYDROLOGY MONITORING PROGRAM
1980 REPORT YEAR
GROUND WATER PHYSICAL DATA

STA	MO	DAY	YR	WL	TEMP	COND	pH
GS-M2U	1	30	80	217.20	11.2	1550	9.2
GS-M2U	5	7	80	217.00	12.5	1500	9.4
GS-M3U	1	30	80	11.80	7.9	1210	9.7
GS-M3U	3	17	80	11.60	12.0	1450	9.6
GS-M3U	5	13	80	11.70	7.0	1300	9.7
GS-10U	1	30	80	430.00	12.9	1950	7.4
GS-10U	2	25	80	429.30	12.2	2050	7.2
GS-10U	3	19	80	428.30	13.6	1950	7.5
GS-10U	4	23	80	*	13.8	2000	8.5
GS-10U	5	14	80	432.60	12.5	2100	7.2
GS-15U	1	3	80	308.30	12.4	2350	7.6
GS-15U	2	25	80	307.90	12.0	1950	7.5
GS-15U	3	17	80	307.50	11.5	2100	7.6
GS-15U	4	23	80	306.50	13.8	2300	8.2
GS-15U	5	13	80	306.10	13.0	2300	7.3
GS-9U	12	27	79	334.10	10.9	1220	7.4
GS-9U	1	30	80	342.00	11.2	1150	7.0
GS-9U	2	26	80	346.60	11.8	820	7.5
GS-9U	3	19	80	349.70	11.0	1100	7.4
GS-9U	4	23	80	351.80	14.0	1250	8.1
GS-9U	5	14	80	350.00	11.0	1250	7.4
GS-M10U	4	22	80	57.95	3.8	1350	7.4
GS-M10U	5	8	80	*	13.5	1375	7.5
GS-M11U	4	22	80	25.15	7.7	1300	7.6
GS-M11U	5	8	80	*	13.2	1350	7.5
GS-M12U	5	8	80	*	13.8	1575	7.1
GS-M6U	5	7	80	*	13.0	1200	7.4
GS-D5U	7	1	80	*	16.8	1350	7.9
GS-D5U	7	8	80	*	17.0	1325	7.9
GS-D5U	7	15	80	*	18.0	1300	7.7
GS-D5U	7	28	80	*	17.0	1350	7.4
GS-D6U	7	1	80	*	17.0	1375	8.0
GS-D6U	7	8	80	*	17.0	1375	7.7
GS-D6U	7	15	80	*	17.8	1375	7.7
GS-D6U	7	25	80	*	18.0	1300	7.5
GS-D8U	7	1	80	*	16.8	1350	7.9
GS-D8U	7	8	80	*	17.0	1350	7.9
GS-D8U	7	15	80	*	17.0	1375	7.8
GS-D8U	7	21	80	*	16.0	1400	7 8

RIO BLANCO HYDROLOGY MONITORING PROGRAM
1980 REPORT YEAR
STA=CE-707U



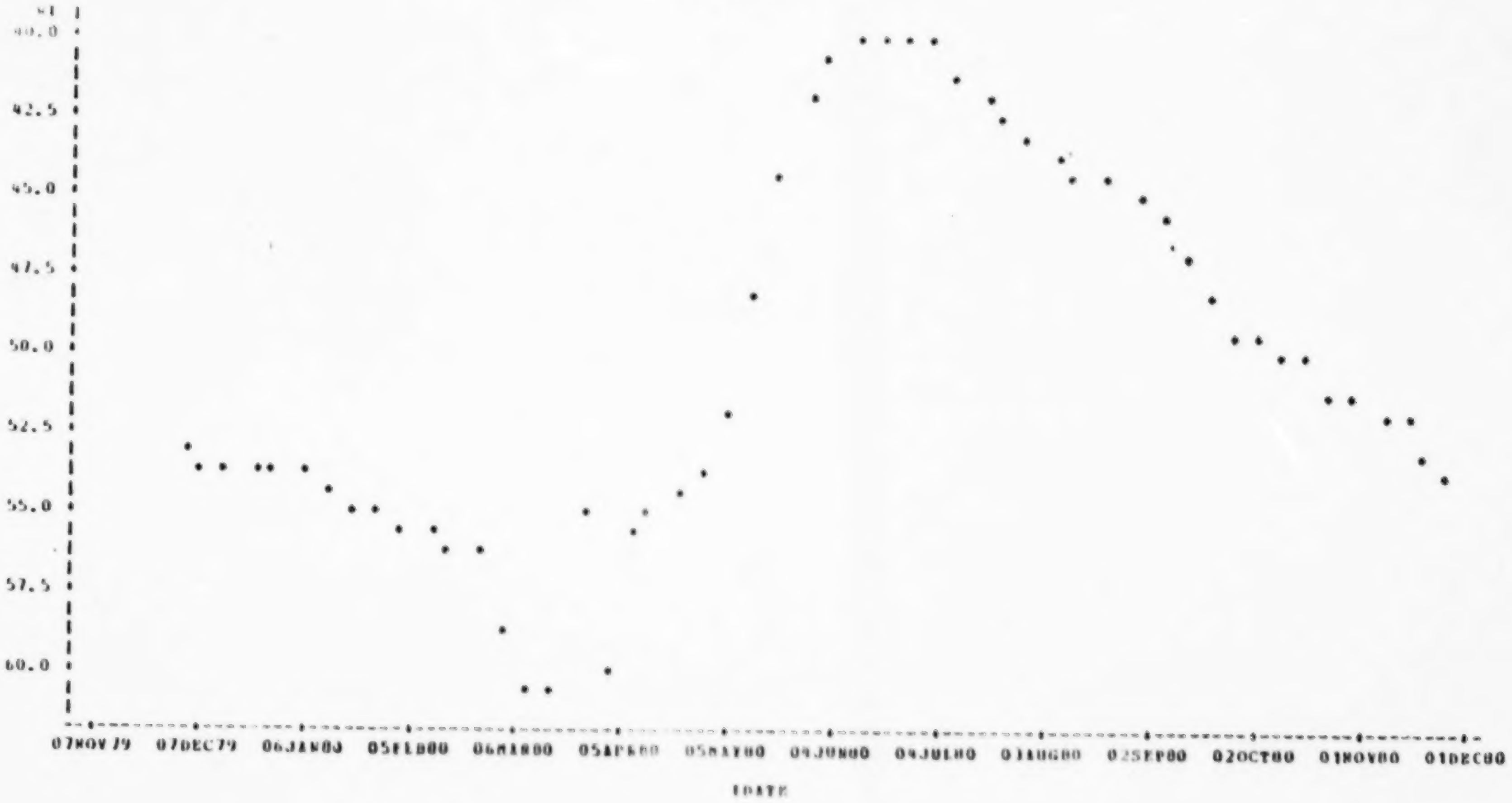
NOTE: 112 OBS HIDDEN

APPENDIX III Figure 1

584

RIO BLANCO HYDROLOGY MONITORING PROGRAM
1980 REPORT YEAR
STA-CE-7000

20:36 MONDAY, MARCH 9, 1981 37



APPENDIX III Figure 2

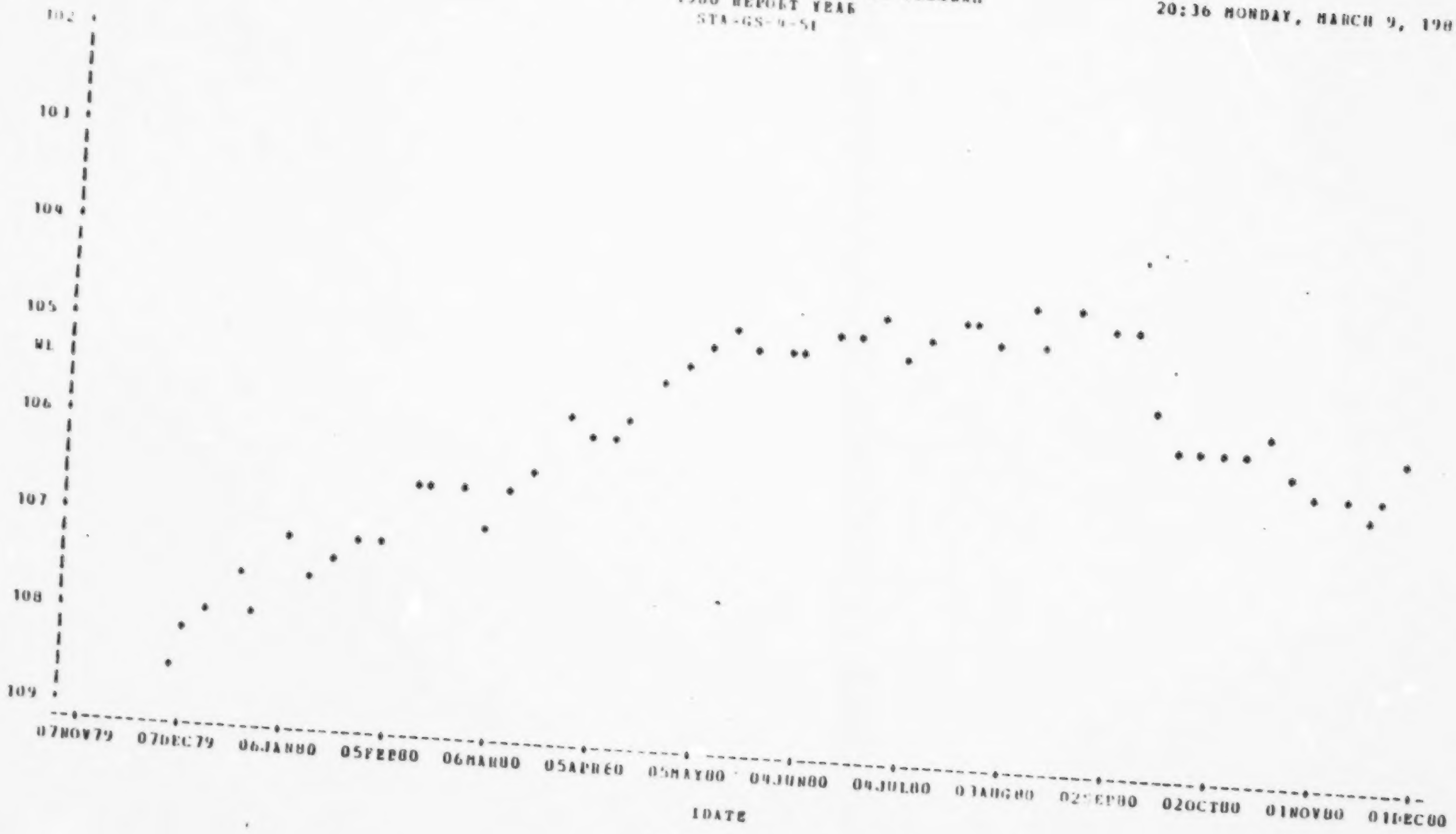
RIO BLANCO HYDROLOGY MONITORING PROGRAM
1980 REPORT YEAR
GROUND WATER PHYSICAL DATA

STA	MO	DAY	YR	WL	TEMP	COND	pH
CE-702L	1	27	80	40.1	14.6	1800	8.0
CE-702L	2	23	80	40.4	11.2	1475	7.2
CE-702L	5	7	80	37.0	16.0	1800	8.5
CE-709L	1	26	80	165.0	11.3	1200	8.5
CE-709L	5	14	80	163.0	12.0	1800	8.4
GS-M4L	12	19	79	548.4	13.5	1375	8.9
GS-M4L	1	30	80	548.1	13.1	1450	8.8
GS-M4L	2	26	80	548.1	13.8	1900	7.4
GS-M4L	4	23	80	546.8	14.4	2050	8.0
GS-M4L	5	7	80	546.9	14.8	2100	7.6
GS-15L	1	30	80	372.8	12.8	2225	9.0
GS-15L	5	13	80	371.2	15.0	3200	8.0
TO-2L	1	30	80	543.1	13.1	1450	8.8
TO-2L	2	26	80	548.4	13.8	1900	7.4
TO-2L	4	23	80	546.8	14.4	2050	8.0
TO-2L	5	7	80	546.9	14.0	2100	7.6

589

RIO BLANCO HYDROLOGY MONITORING PROGRAM
1980 REPORT YEAR
STA-GS-9-51

20:36 MONDAY, MARCH 9, 1981 72

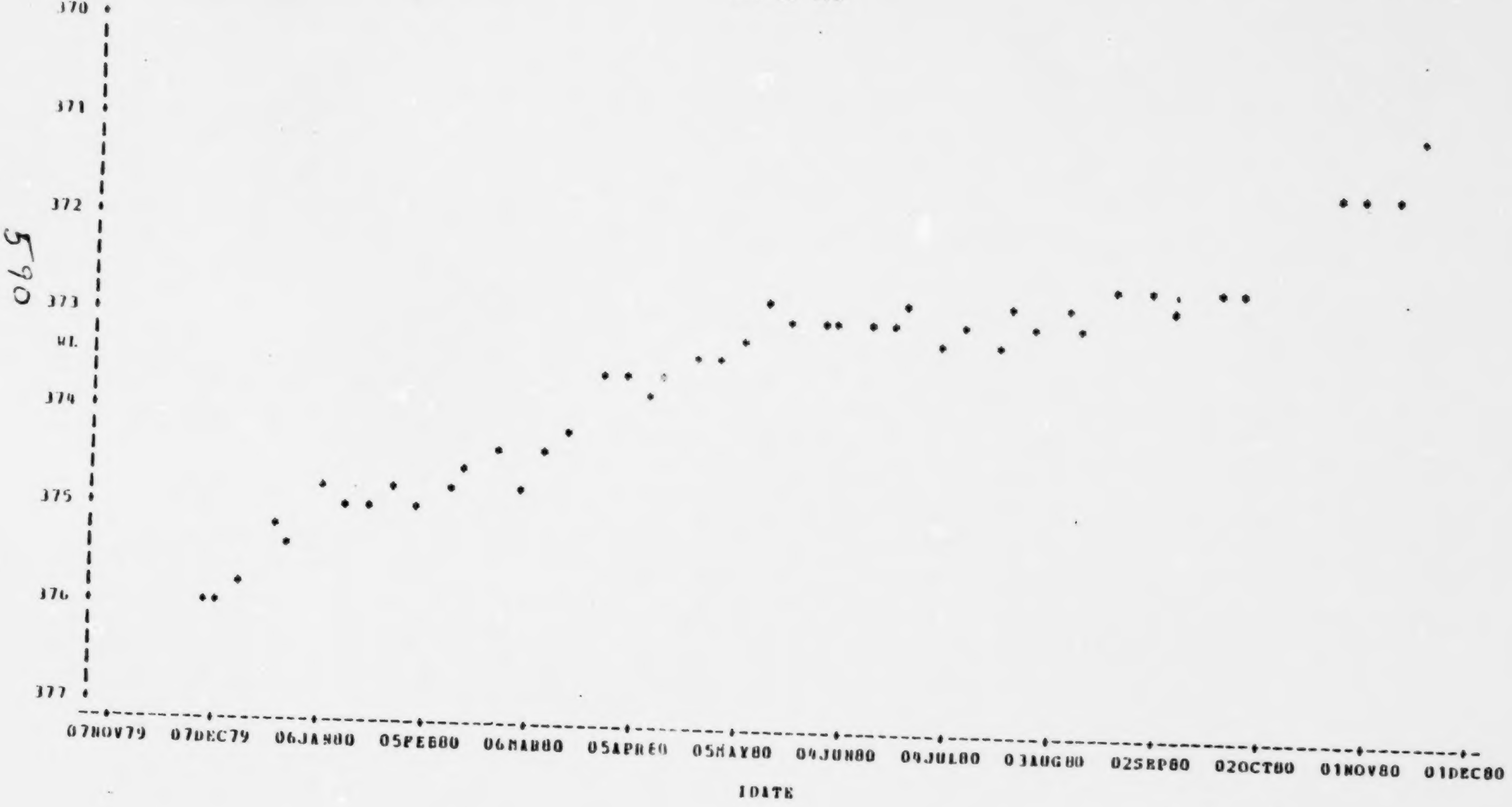


APPENDIX III Figure 7

RIO BLANCO HYDROLOGY MONITORING PROGRAM
1980 REPORT YEAR
STA=GS-17L

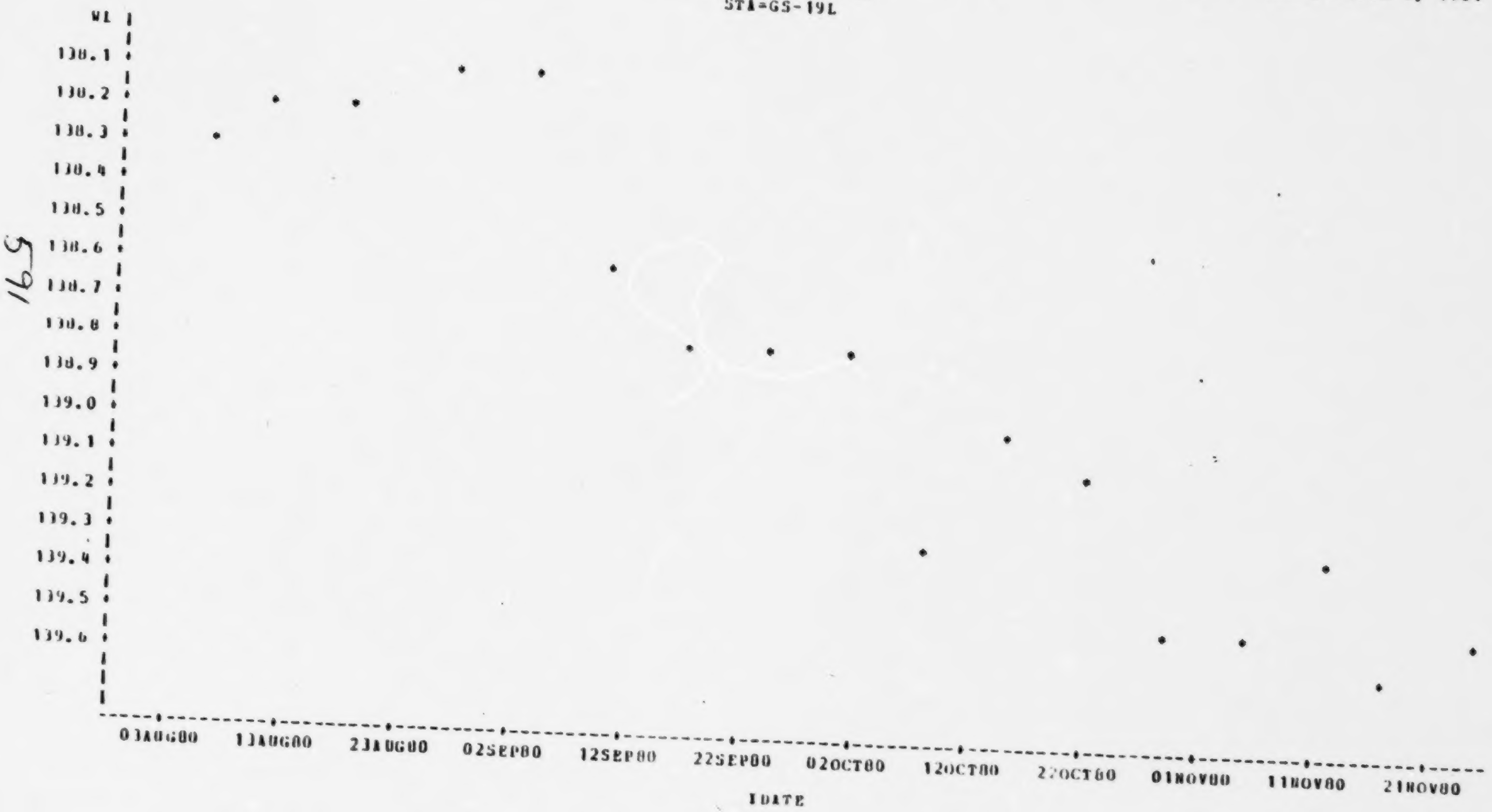
20:36 MONDAY, MARCH 9, 1981 70

590



APPENDIX III Figure 4

RIO BLANCO HYDROLOGY MONITORING PROGRAM
1980 REPORT YEAR
STA=GS-19L



APPENDIX III Figure 5

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                                                                  RIO BLANCO HYDROLOGY MONITORING PROGRAM                          1:32 SATURDAY, MARCH 7, 1981   99
                                                                     UPPER AQUIFER WATER QUALITY DATA

---------------------------------------------------------------------------- RPTYR=80 ---------------------------------------------------------------------------------

                                   S
                                   P
                         D
                         E     T   C                  H
 S               D       P     E   O                  C   C
 T           M   A   Y   T     M   N    P         A   O   O                                 S
 A           O   Y   R   H     P   D    H         L   3   3        C        M   N        C   O                A                 M
                                                  K                A        G   A   K    L   4    P         S             B  O L V    S       H      D    T
                                                                                                                                        E       G      O    D
                                                                                                                                                       C    S
 CE-705AU   11  24  80      .  10.5 1240 7.00 514 607 -1.00   66.00   71.00 150 0.24  3.05 286 0.430    .     0.290 . .    .       .      5  932
 CE-7070    12  26  79  247.0  10.3 1250  .   489 592   .     87.00   82.00 140 0.93 10.00 275 0.098    .     0.160 . .    .       .      .    .
 CE-7070     1  30  80  247.3  10.9 1350 7.50 485 592 -0.10   90.00  106.00  75 2.30 13.00 306 0.100 -0.01 -0.100 . . -0.01  -0.001    3  909
 CE-7070     3  17  80  236.2   9.0 1650 8.00 375 454 -1.00  120.00  103.00 133 1.75 25.00 600 0.230    .     0.320 . .    .       .      .    .
 CE-7070     4  24  80  228.0  11.0 1500 8.20 340 411 -1.00   85.00   91.00  85 1.75 23.50 400 0.190    .     0.170 . .    .       .      .    .
 CE-7070     5  14  80  232.1  10.0 1425 7.30 367 437 -0.01   94.39   93.44 110 1.50 22.00 440 0.335    .  .  0.230 . .    .       .      .    .
 CE-7070     6  14  80      .  10.8 1475 7.20 441 534   .    110.00   88.10 120 1.75 23.00 428 0.300    .     0.177 . .    .       .      .    .
 CE-7070     8  28  80      .  13.0 1440 7.70 408 570 -1.00   93.00   83.00 137 1.14 16.80 378 0.240    .     0.270 . .    .       .      . 1052
 CE-7070     9  30  80      .  11.5 1450 7.80 467 544 -1.00   91.00   78.00 133 0.91 16.00 358 0.190    .     0.420 . .    .       .      . 1000
 CE-7070    10  23  80      .  10.5 1340 7.75 482 560 -1.00   93.00   75.00 133 1.00 13.90 316 0.270    .     0.230 . .    .       .     14  956
 CE-7070    11  25  80      .  10.7 1340 7.90 471 549 -1.00   82.00   74.00 130 1.07 10.10 368 0.210    .     0.230 . .    .       .      6  976
 CE-7090    12  27  79  242.5   9.2 1700 7.40 441 534   .    132.00   99.40 153 0.92  4.00 573 0.298    .     0.105 . .    .       .      .    .
 CE-7090     1  30  80  244.6   9.4 1650 7.00 445 543 -0.10  128.00  124.00  80 2.00 18.00 500 0.100 -0.01 -0.100 . . -0.01  -0.001    6 1200
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                              RIO BLANCO HYDROLOGY MONITORING PROGRAM
                                UPPER AQUIFER WATER QUALITY DATA                 1:32 SATURDAY, MARCH 7, 1981  100
------------------------------------------------------ RPTYR=80 ------------------------------------------------------

  STA       MO   DAY   YR   DEPTH   TEMP   SP_COND    PH    ALK   HCO3    CO3       CA        MG      NA

CE-7090      2    26   80   245.5   11.2    1700     7.30     .     .       .         .         .     110
CE-7090      3    17   80   244.8   10.8    1500     7.60   440   532   -1.00    123.00     87.00    135
CE-7090      4    23   80   245.8   11.8    1675     8.00   447   541   -1.00    121.00     90.00    145
CE-7090      5    14   80   247.2   10.0    1700     7.30   412   491   -0.01    111.00    111.00    156
CE-7090      6    14   80     .     11.1    1675     7.10   441   534     .      101.00     97.30    165
CE-7090      8    21   80     .     14.0    1650     7.42   531   609   -1.00    136.00     96.00    154
CE-7090      8    28   80     .     12.5    1480     7.40   501   583   -1.00    124.00     94.00    161
CE-7090      9    30   80     .     11.7    1600     7.50   497   580   -1.00    131.00     88.00    140
CE-7090     11    25   80     .     10.5    1490     7.50   497   501   -1.00    105.00     86.00    150
GS-M10       7    24   80     .     15.0    1400     7.70   396   460   -1.00     50.60     42.30    243
GS-M10      12    19   79   655.8   13.5    1250     8.30   339   410     .       52.09     42.85    215
GS-M10       1    30   80   655.3   15.6    1275     7.50   349   427   -0.10     80.00     37.00    185
GS-M10       2    26   80   654.9   13.8    1375     7.20     .     .       .         .         .     195

  STA        K      CL     SO4      F       AS       B      MOL     V      SE       HG     DOC    TDS

CE-7090    1.03      .       .      .        .        .       .      .      .        .       .      .
CE-7090    0.75   15.00    470   0.390      .     0.350      .      .      .        .       .      .
CE-7090    0.50   18.00    610   0.480      .     0.270      .      .      .        .       .      .
CE-7090    1.03   20.00     .    0.550      .     0.160      .      .      .        .       .      .
CE-7090    1.25   19.00    586   0.630      .     0.235      .      .      .        .       .      .
CE-7090    0.43   23.40    463   0.390    0.01    0.300     0.4   -0.5  -0.01   -0.300     29   1248
CE-7090    0.39   22.00    500   0.360      .     0.330      .      .      .        .       .    1204
CE-7090    0.52   19.60    458   0.330      .     0.510      .      .      .        .       .    1212
CE-7090    0.34    9.85    466   0.130      .     0.330     .       .      .        .       5   1212
GS-M10     0.68   10.80    385  -0.100   -0.01   -0.010    -0.1   -0.5  -0.01   -0.300     15   1012
GS-M10     0.73   10.40    388   0.161      .     0.110      .      .      .        .       .      .
GS-M10     1.03   10.00    350  -0.100   -0.01    0.100      .      .    -0.01   -0.001     .     850
GS-M10     0.50     .       .      .        .        .       .      .      .        .       .      .
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                                     RIO BLANCO HYDROLOGY MONITORING PROGRAM                1:32 SATURDAY, MARCH 7, 1981  132
                                   UPPER AQUIFER MISCELLANEOUS WATER QUALITY DATA

------------------------------------------------------------ RPTYR=80 ------------------------------------------------------------

    STA    MO DAY YR  NH3   NO2   NO3    NH3N KJELN  PO4  ORTHOP SIO2   SH   HARD  CYN   PHENOL COD MBAS TCOLI FCOLI O_G ALPHA BETA

  CE-7070  6 14  80    .     .  6.325   .     .     .      .    21.75   .      .    .      .     .   .     .     .    .    .     .
  CE-7070  8 20  80    .  -0.1   .      .     .     .      .    11.00   .    574    .      .     .   .     .     .    .    .     .
  CE-7070  9 30  80    .   0.1   .      .     .     .      .    11.00   .    548    .      .     .   .     .     .    .    .     .
  CE-7070 10 23  80    .  -0.1   .     0.2    .   -0.01    .    11.00   .    541    .      .     .   .     .     .    .    .     .
  CE-7070 11 25  80    .   0.1   .     3.1    .    0.01    .    10.00   .    509    .      .     .   .     .     .    .    .     .
  CE-7090 12 27  79    .     .  0.385   .     .     .      .    32.00   .      .    .      .     .   .     .     .    .    .     .
  CE-7090  1 30  80 -0.3     .  0.600   .     .   -0.10    .    25.00 -0.2     . -0.01 -0.001  25   .     .     .    .   12     .
  CE-7090  2 26  80    .     .  0.538   .     .     .      .      .     .      .    .      .     .   .     .     .    .    .     .
  CE-7090  3 17  80    .     .  0.026   .     .     .      .    26.50   .    664    .      .     .   .     .     .    .    .     .
  CE-7090  4 23  80    .     .  0.060   .     .     .      .    26.50   .    658    .      .     .   .     .     .    .    .     .
  CE-7090  5 14  80    .     .  0.067   .     .     .      .    30.20 613.0    .    .      .     .   .     .     .    .    .     .
  CE-7090  6 14  80    .     .  0.069   .     .     .      .    29.50   .      .    .      .     .   .     .     .    .    .     .
  CE-7090  8 21  80    .  -0.1   .     0.1    .    0.07    .    34.00  1.5   735 -0.05 -0.050  21   .     .     .    .    .     .
  CE-7090  8 28  80    .  -0.1   .      .     .     .      .    25.00   .    697    .      .     .   .     .     .    .    .     .
  CE-7090  9 30  80    .  -0.1   .      .     .     .      .    30.00   .    689    .      .     .   .     .     .    .    .     .
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                                        RIO BLANCO HYDROLOGY MONITORING PROGRAM                 1:32 SATURDAY, MARCH 7, 1981  167
                                           UPPER AQUIFER TRACE ELEMENT DATA

---------------------------------------------------------------- SPTYR=80 ----------------------------------------------------------------

   STA     MO  DAY  YR   AL     AS      CD      CR    CU    FE      PB     HG       SE     ZN   MN  BA  AG    NI     LI   BR    BE  BOL  SI   V

 CE-7070    3   17  80   .      .       .       .     .     0.21    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7070    4   24  80   .      .       .       .     .     0.33    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7070    5   14  80   .      .       .       .     .     0.14    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7070    6   14  80   .      .       .       .     .     0.27    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7070    8   28  80   .      .       .       .     .    10.50    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7070    9   30  80   .      .       .       .     .    -0.05    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7070   10   23  80   .      .       .       .     .     1.45    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7070   11   25  80   .      .       .       .     .     0.07    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7090   12   27  79   .      .       .       .     .      .      .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7090    1   30  80  0.3  -0.01   -0.01   -0.01    .    -0.05   0.04  -0.001   -0.01   0.1   .   .   .   -0.01    .  -0.1    .   .   1.3   .
 CE-7090    2   26  80   .      .       .       .     .     0.03    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7090    3   17  80   .      .       .       .     .     0.38    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7090    4   23  80   .      .       .       .     .     0.12    .      .        .      .    .   .   .     .      .    .     .   .    .    .
 CE-7090    5   14  80   .      .       .       .     .     0.11    .      .        .      .    .   .   .     .      .    .     .   .    .    .
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                                   RIO BLANCO HYDROLOGY MONITORING PROGRAM                1:32 SATURDAY, MARCH 7, 1981  19
                                     LOWER AQUIFER WATER QUALITY DATA
------------------------------------------------------------- RPTYR=80 -------------------------------------------------------

                                 S
                                 P
                     D           _
                     E     T     C              H
S           D        P     E     O         A    C      C                                      S                     M                   D    T
T        M  A  Y     T     M     N    P    L    O      O      C      M     N           C      O            A        O      S       H    O    D
A        O  Y  R     H     P     D    H    K    3      3      A      G     A    K      L      4      F     S     B  L V    E       G    C    S
CE-702L  2 25 80   40.4   11.2 1475 7.20    .    .       .      .     .   140 1.25       .      .      .     .    .  .  .      .       .  .    .
CE-702L  5  7 80   37.0   16.0 1800 8.60  798  889   42.00  11.00   6.7   440 2.30   21.00  151.0  32.00 -0.01 1.10  .  .  -0.01  -0.001 11 1150
CE-702L  8  1 80      .   12.0 1920 8.20  914 1077   -1.00  12.10  15.4   495 0.65   33.30  200.0   8.17     . 1.36  .  .      .       .  . 1396
CE-709L  5 15 80  163.6   12.0 1800 8.40 2030 2190  144.00  20.00  25.0   950 4.00   32.00   56.0  12.00 -0.01 1.60  .  .  -0.01  -0.001 15 3640
CE-709L  8  7 80      .   17.5 2000 8.35  980 1165   -1.00  23.00  26.6   434 0.75   13.60  149.0   9.61     . 0.96  .  .      .       . 28 1244
GS-15L   1 30 80  372.8   12.8 2225 9.00  981 1010   90.00   6.70  68.0   450 5.00   33.00  260.0  20.00     .    .  .  .      .       .  .    .
GS-15L   5 13 80  370.9   15.0 3200 8.00 1730 1860   -0.01  15.00  22.0   940 4.50   64.00  162.0  53.00 -0.01 2.00  .  .  -0.01  -0.001 21 2320
GS-15L   8  1 80      .   17.5 4000 8.30 1968 2326   -1.00   5.53  32.5   921 2.13  112.00  177.0  55.20     . 1.79  .  .      .       .  . 2500
GS-15L  10 21 80      .   13.2 4206 8.20 2470 2931   -1.00   2.74  21.8  1200 1.88   71.50   85.6   5.31     . 2.24  .  .      .       . 39 3020
GS-15L  11 24 80      .   14.0 1690 9.50  626  465   13.40   3.10  60.0   340 2.30    9.95  524.0   0.45     . 0.35  .  .      .       .  5 1136
GS-17L   5 13 80  372.8   17.0 2300 8.40 1052 1130   76.00   9.80  23.0   533 3.70   53.00  104.0  17.00 -0.01 3.40  .  .  -0.01   0.001 12 1450
GS-17L   7 15 80      .   19.0 2400 8.50 1312 1486    2.67   3.90  19.0   632 2.30   60.40  141.0   1.96     . 1.36  .  .      .       .  . 1660
GS-18L   7 16 80      .  -61.6 3500 8.30 2463 2050   -1.00   2.08   7.0  1098 2.40   52.00   85.6   2.76     . 1.02  .  .      .       .  . 2824

N=13
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                                    RIO BLANCO HYDROLOGY MONITORING PROGRAM                     1:32 SATURDAY, MARCH 7, 1981  200
                                   LOWER AQUIFER MISCELLANEOUS WATER QUALITY DATA

---------------------------------------------------------------- RPTYR=80 ----------------------------------------------------------------

   STA     MO DAY YR NH3  NO2   NO3  NH3N KJELN  PO4  ORTHOP SIO2  SN    HARD    CYN  PHENOL COD MBAS TCOLI FCOLI O_G ALPHA BETA

CE-702L   2 25  80   .     .    2.34  .     .     .      .     .    .      .       .      .     .   .     .     .    .    .    .
CE-702L   5  7  80 -0.3    .   -0.10  .     .   -0.10    .   10.0 -0.2     .    -0.01 -0.001  11   .     .     .    .    2    .
CE-702L   8  1  80   .   -0.1    .    .     .     .      .   14.0   .    93.60    .      .     .   .     .     .    .    .    .
CE-709L   5 15  80 -0.3    .   -0.10  .     .   -0.10    .   12.0  0.2     .    -0.01 -0.001  11   .     .     .    .    .    .
CE-709L   8  7  80   .    2.5    .    .     .     .      .   10.0   .   167.00    .      .     .   .     .     .    .    .    .
GS-15L    1 30  80   .     .     .    .     .     .      .    3.4   .      .       .      .     .   .     .     .    .    .    .
GS-15L    5 11  80  1.7    .   -0.10  .     .   -0.10    .    6.4  0.2     .    -0.01 -0.001  11   .     .     .    .    .    .
GS-15L    8  1  80   .   -0.1    .    .     .     .      .    6.0   .   140.00    .      .     .   .     .     .    .    .    .
GS-15L   10 21  80   .   -0.1    .   1.8    .    0.01    .    9.0   .    96.57    .      .     .   .     .     .    .    .    .
GS-15L   11 24  80   .   -0.1    .   0.2    .    0.04    .   -0.5   .   255.00    .      .     .   .     .     .    .    .    .
GS-17L    5 13  80  4.5    .   -0.10  .     .   -0.10    .    5.0  0.2     .    -0.01 -0.001  40   .     .     .    .    7    .
GS-17L    7 15  80   .    0.2    .    .     .     .      .   -0.5   .    87.94    .      .     .   .     .     .    .    .    .
GS-18L    7 16  80   .    0.4    .    .     .     .      .   10.0   .    34.01    .      .     .   .     .     .    .    .    .

N=13
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                                        RIO BLANCO HYDROLOGY MONITORING PROGRAM              1:32 SATURDAY, MARCH 7, 1981  226
                                           LOWER AQUIFER TRACE ELEMENT DATA

------------------------------------------------- RPTYR=80 ------------------------------------------------------------------

  STA     MO DAY  YR    AL     AS     CD     CR    CU    FE     PB     HG      SE     ZN   NB BA AG NI TI   MN   BE MOI  SB   V

CE-702L    2  25  80     .      .      .      .     .    0.05    .      .       .      .    .  .  .  .  .    .    .   .    .   .
CE-702L    5   7  80     .   -0.01  -0.01  -0.01    .    0.16  0.05  -0.001  -0.01   0.05  .  .  .  .  .  -0.1   .   .   0.9  .
CE-702L    8   1  80     .      .      .      .     .    0.27    .      .       .      .    .  .  .  .  .    .    .   .    .   .
CE-709L    5  15  80   -0.1  -0.01  -0.01  -0.01    .    0.43  0.02  -0.001  -0.01   0.08  .  .  .  .  .  -0.1   .   .   0.7  .
CE-709L    8   7  80     .      .      .      .     .    0.20    .      .       .      .    .  .  .  .  .    .    .   .    .   .
GS-15L     1  30  80     .      .      .      .     .     .      .      .       .      .    .  .  .  .  .    .    .   .    .   .
GS-15L     5  13  80    0.2  -0.01  -0.01  -0.01    .    0.18  0.02  -0.001  -0.01   0.06  .  .  .  .  .  -0.1   .   .   0.1  .
GS-15L     8   1  80     .      .      .      .     .    0.13    .      .       .      .    .  .  .  .  .    .    .   .    .   .
GS-15L    10  21  80     .      .      .      .     .    0.06    .      .       .      .    .  .  .  .  .    .    .   .    .   .
GS-15L    11  24  80     .      .      .      .     .   -0.05    .      .       .      .    .  .  .  .  .    .    .   .    .   .
GS-17L     5  13  80    0.2  -0.01  -0.01  -0.01    .    0.50  0.03   0.001  -0.01   0.07  .  .  .  .  .  -0.1   .   .   0.2  .
GS-17L     7  15  80     .      .      .      .     .    0.13    .      .       .      .    .  .  .  .  .    .    .   .    .   .
GS-18L     7  16  80     .      .      .      .     .    0.41    .      .       .      .    .  .  .  .  .    .    .   .    .   .

N=13
```
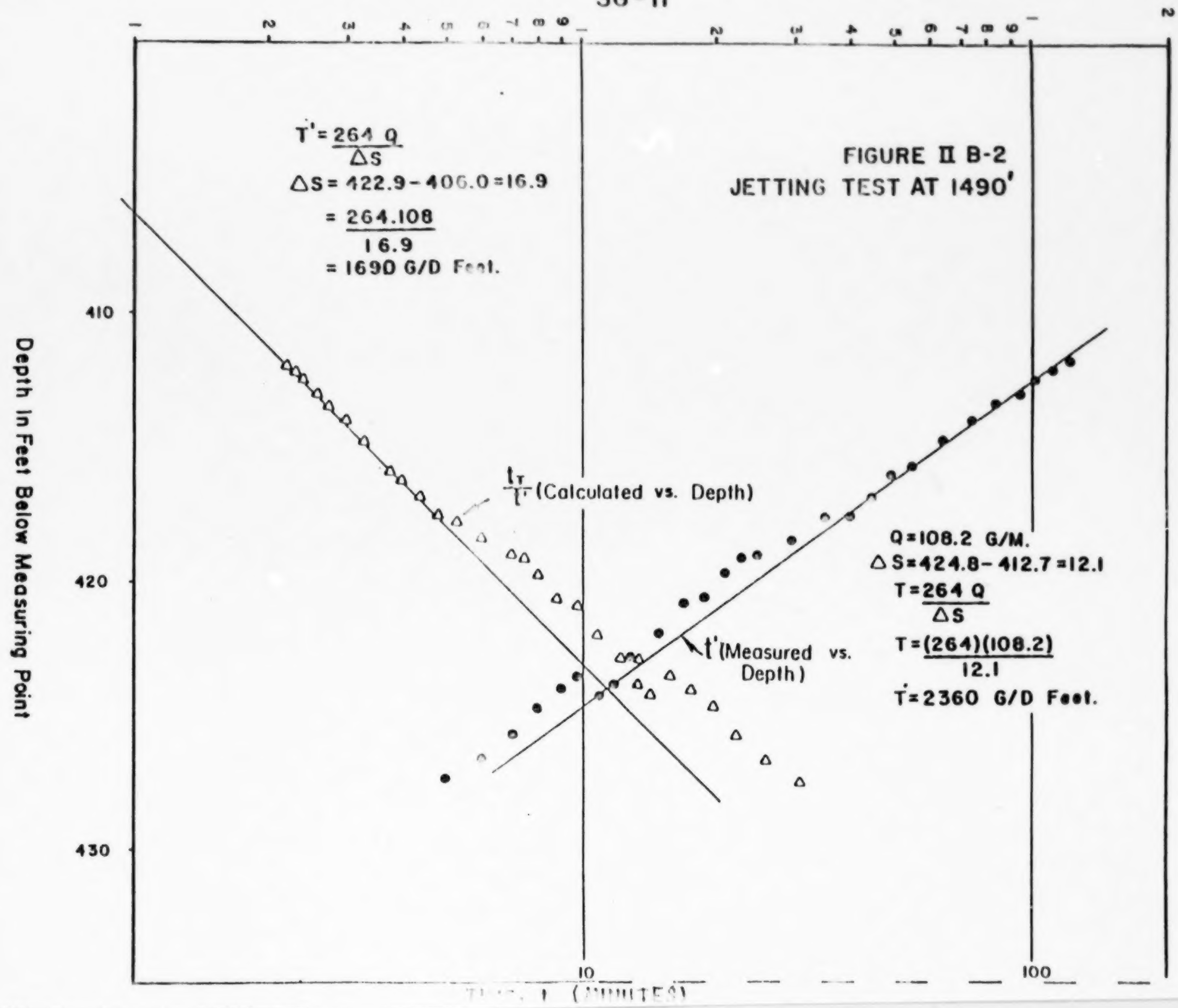
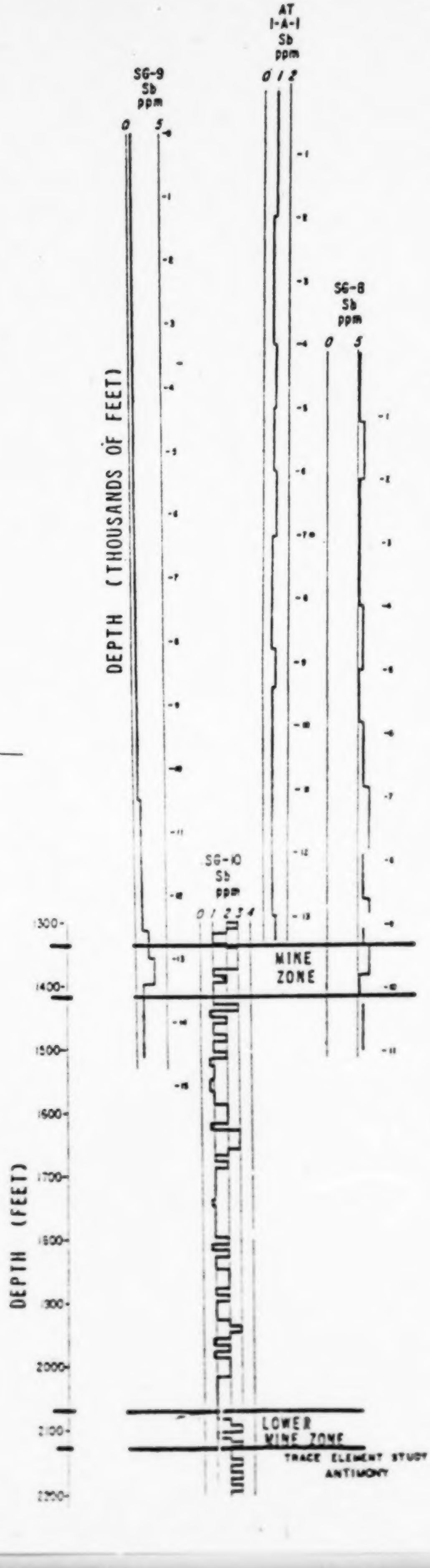

APPENDIX IV

SAMPLE CALCULATION OF AQUIFER TRANSMISSIVITY
SG-II



TRACE ELEMENT STUDY
ANTIMONY HISTOGRAM

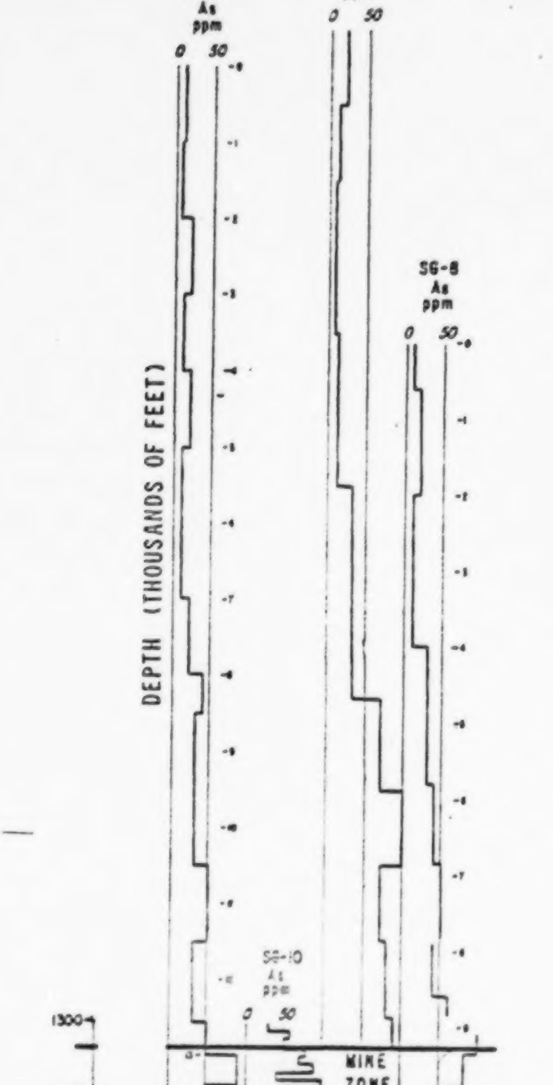
From 1 foot
assays
on cores



APPENDIX IV.2

601

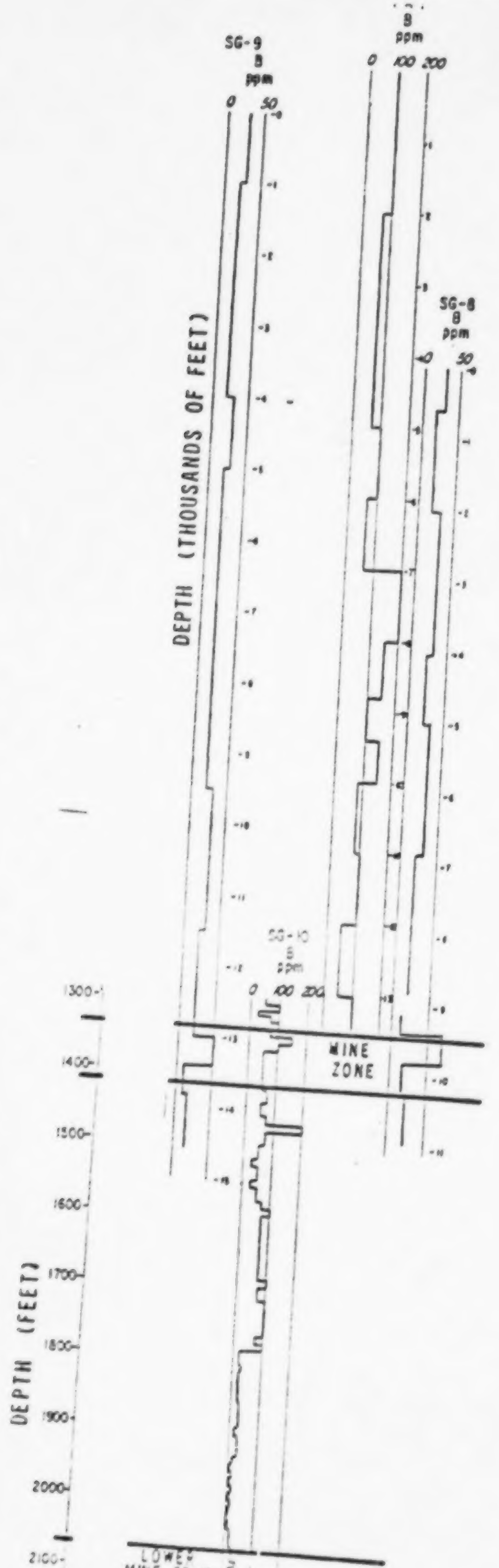
TRACE ELEMENT STUDY
ARSENIC HISTOGRAM



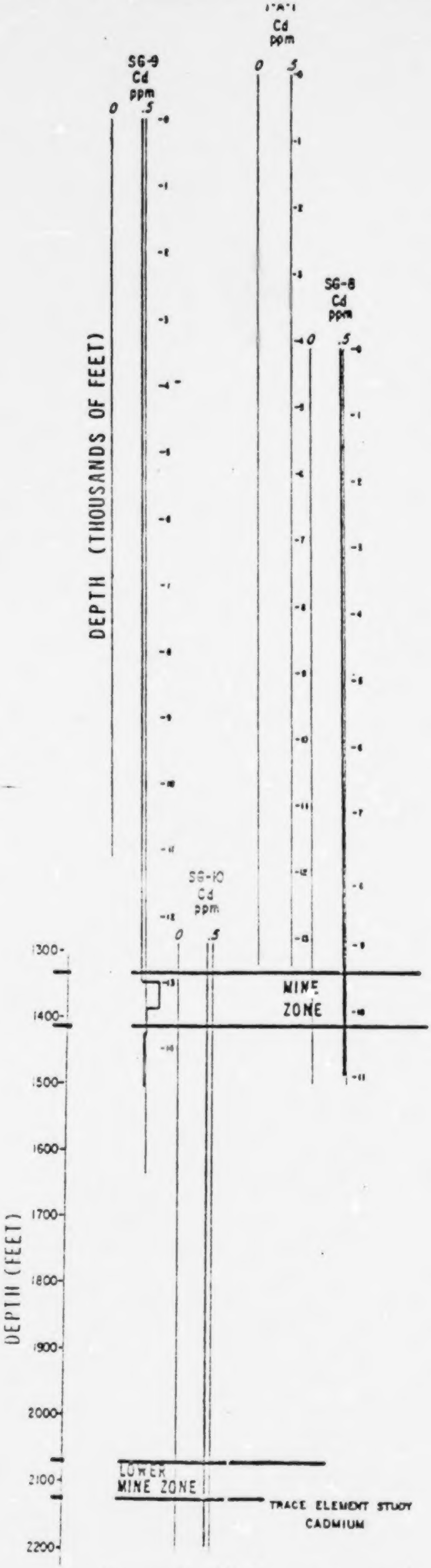
6 D 2

APPENDIX IV.3

TRACE ELEMENT STUDY
BORON HISTOGRAM



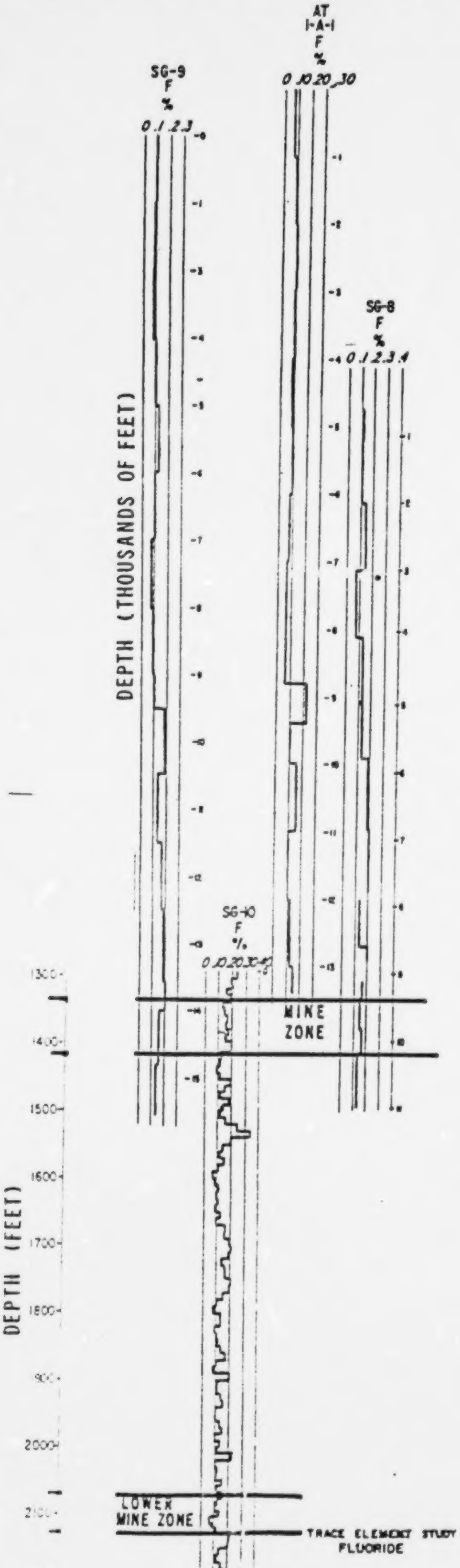
TRACE ELEMENT STUDY
CADMIUM HISTOGRAM



Appendix IV.5 604

APPENDIX IV.5

TRACE ELEMENT STUDY
FLUORIDE HISTOGRAM

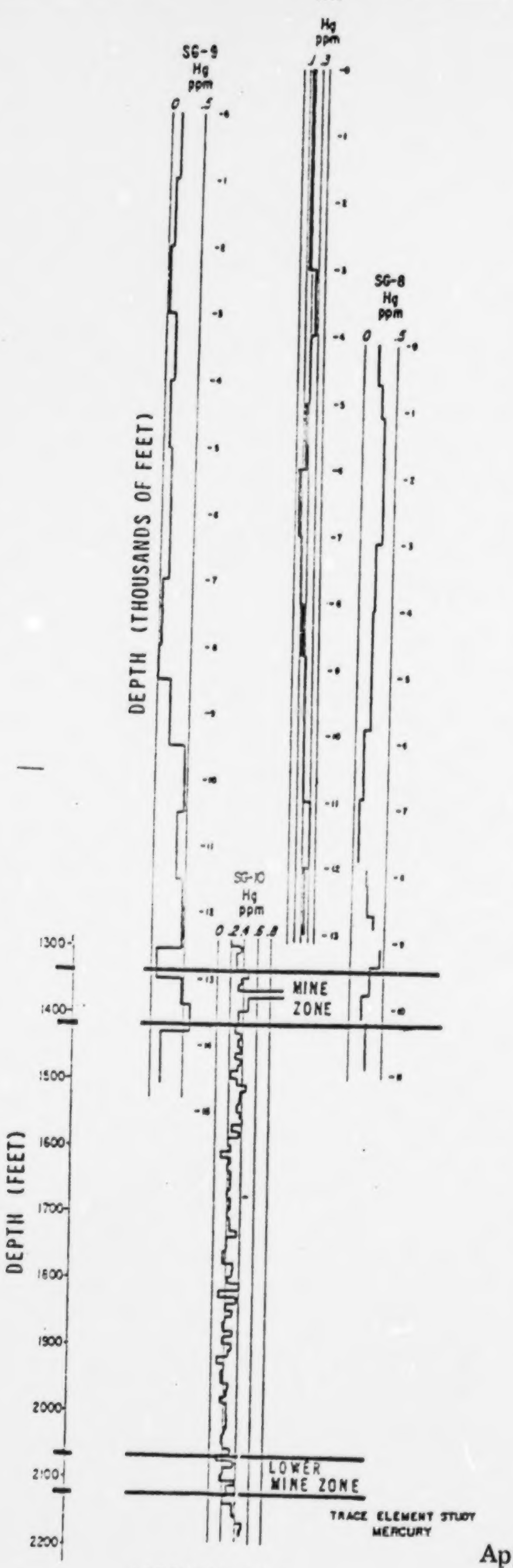


605

Appendix IV. 6

APPENDIX IV.6

TRACE ELEMENT STUDY
MERCURY HISTOGRAM

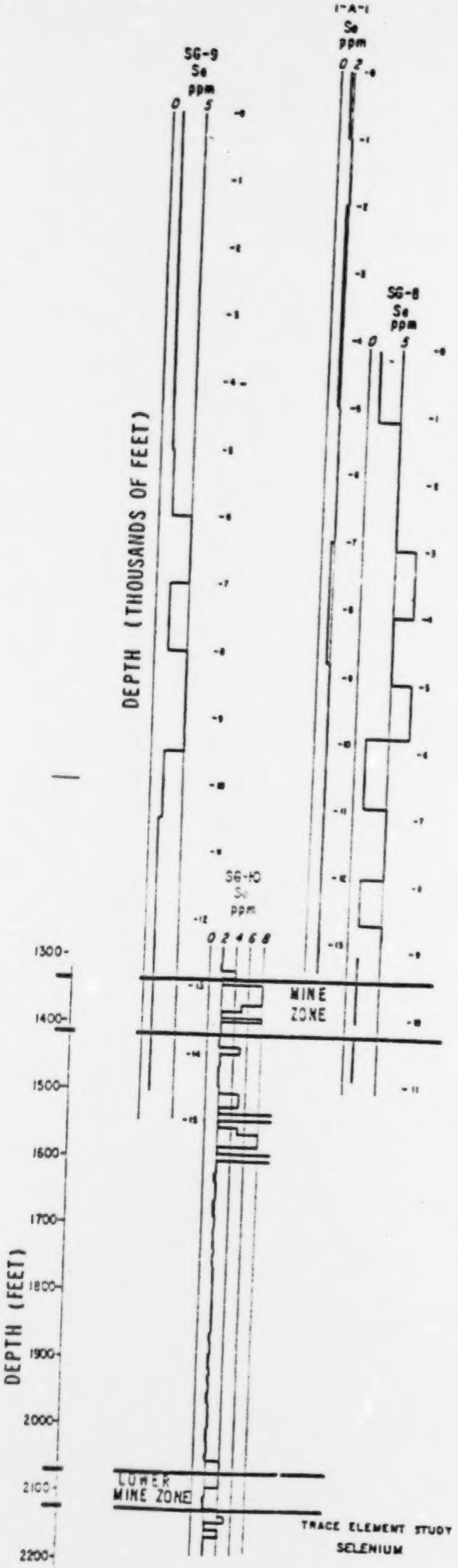


606

Appendix IV. 7

APPENDIX IV.7

TRACE ELEMENT STUDY
SELENIUM HISTOGRAM



Appendix IV. 8

APPENDIX IV.8

FLUORIDE & BORON IN LOWER ZONE

AT-1 PUMPING TEST WATER

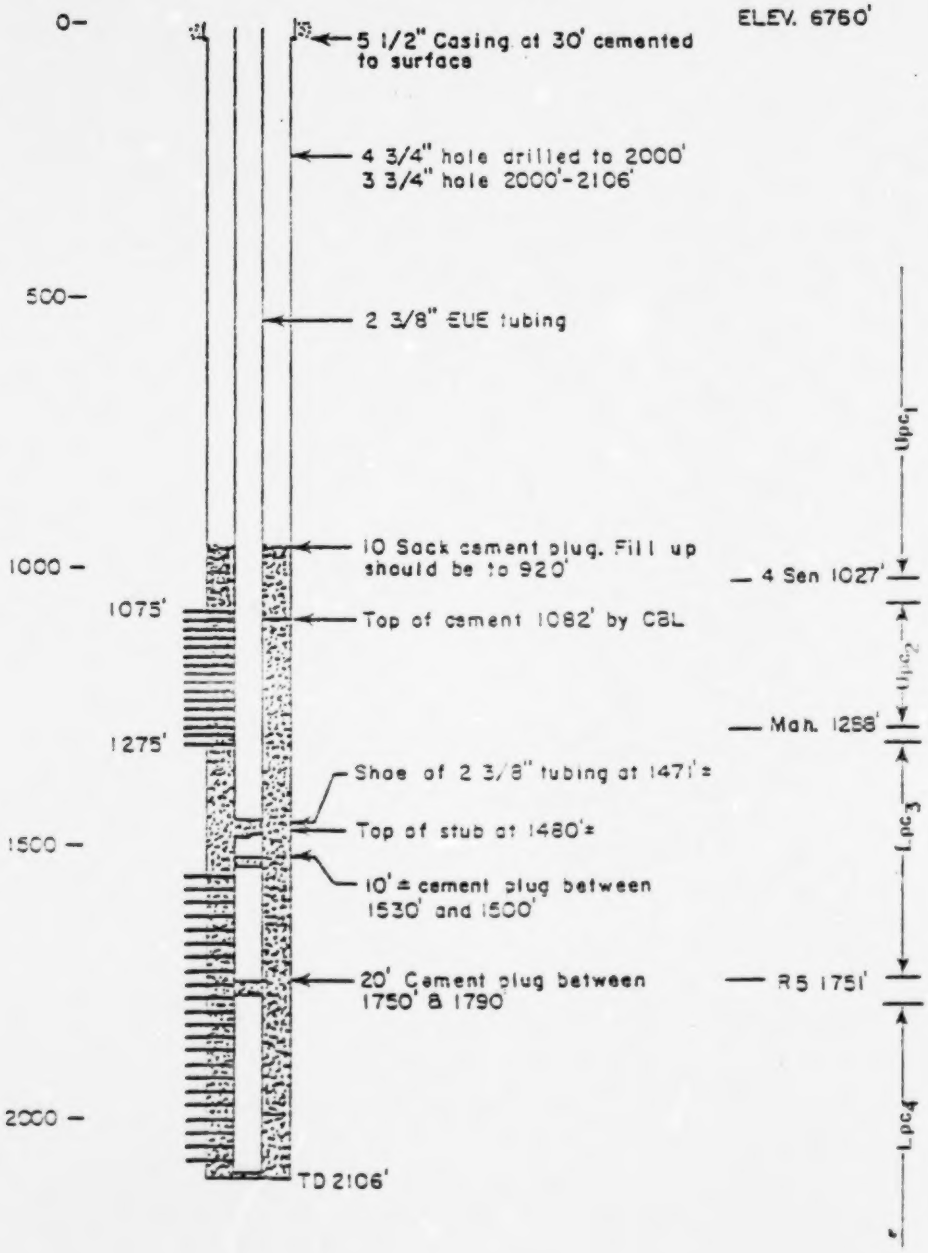
Date - 1975	1/20	2/5	2/23	2/24	2/25	2/27	2/28	3/1	3/3	3/5	3/7	3/19
Fluoride (ppm)	18.0	18.1	20.0	20.1	20.4	18.4	20.4	20.16	19.0	20.0	21.2	23.2
Boron (ppm)	0.65	0.88	1.15	1.10	1.13	1.2	1.6	1.42	2.58	2.02	2.18	2.00

APPENDIX V

FINAL WELL CONFIGURATION

CB-1

FINAL STATUS: Upc$_2$ Monitor

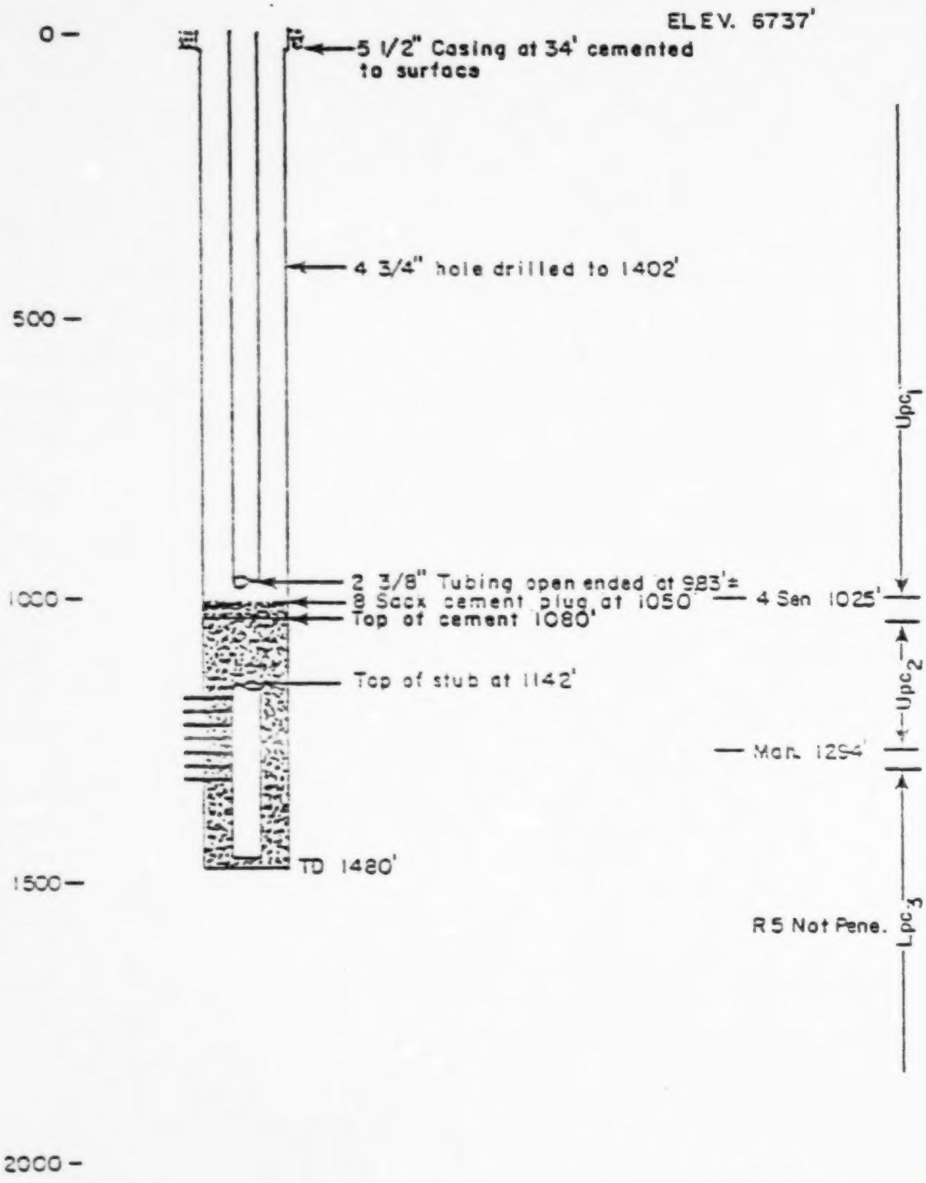

ELEV. 6760'
0-
500-
1000-
1500-
2000-
5 1/2" Casing at 30' cemented to surface
4 3/4" hole drilled to 2000'
3 3/4" hole 2000'-2106'
2 3/8" EUE tubing
10 Sack cement plug. Fill up should be to 920'
1075'
Top of cement 1082' by CBL
1275'
Shoe of 2 3/8" tubing at 1471'±
Top of stub at 1480'±
10'± cement plug between 1530' and 1500'
20' Cement plug between 1750' & 1790'
TD 2106'
Upc1
4 Sen 1027'
Upc2
Man. 1258'
Lpc3
R5 1751'
Lpc4

APPENDIX V.1

FINAL WELL CONFIGURATION

CB-2

FINAL STATUS: Upc_1 Monitor

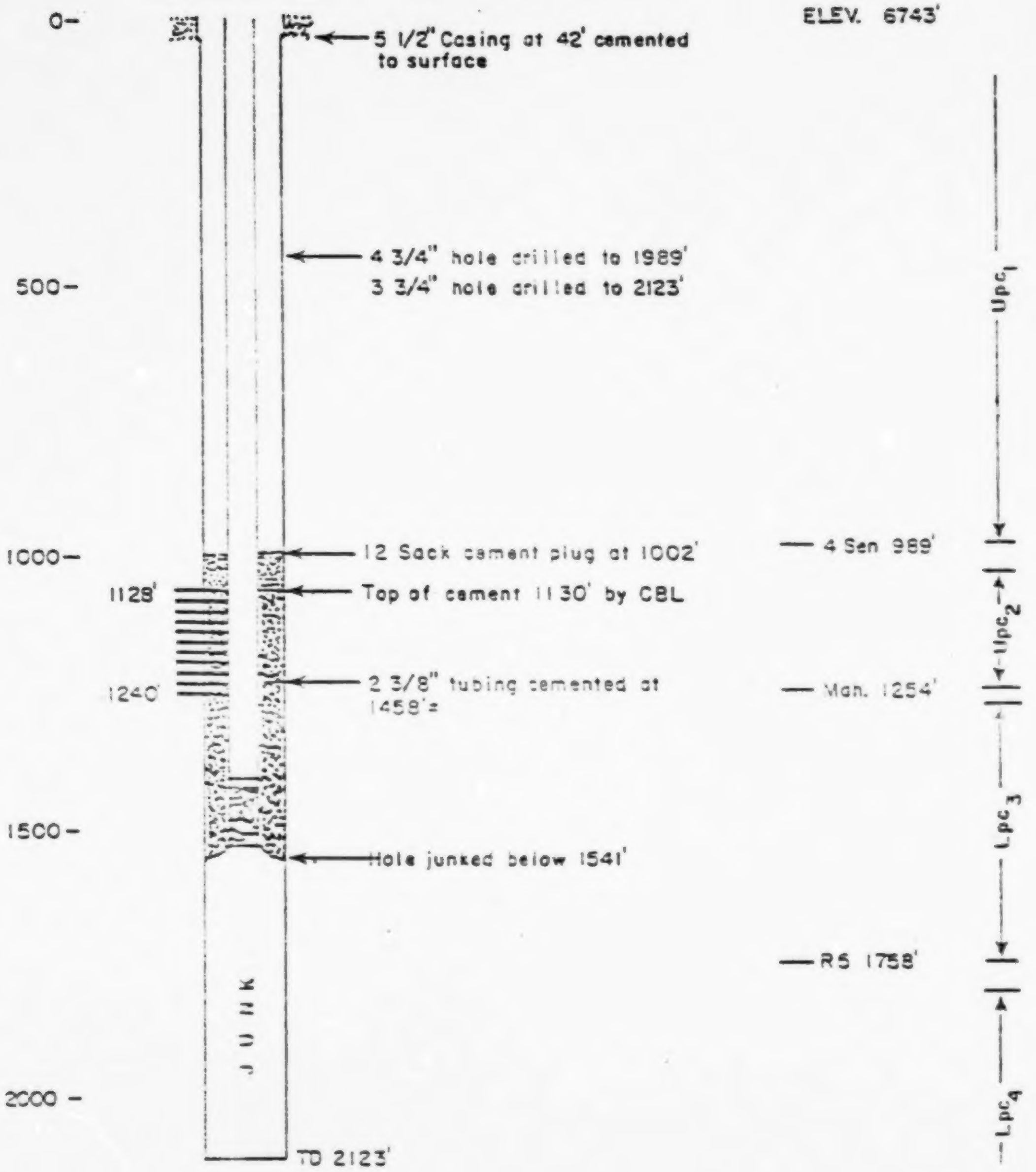


APPENDIX V.2

FINAL WELL CONFIGURATION

CB-3

FINAL STATUS: Upc_2 Monitor

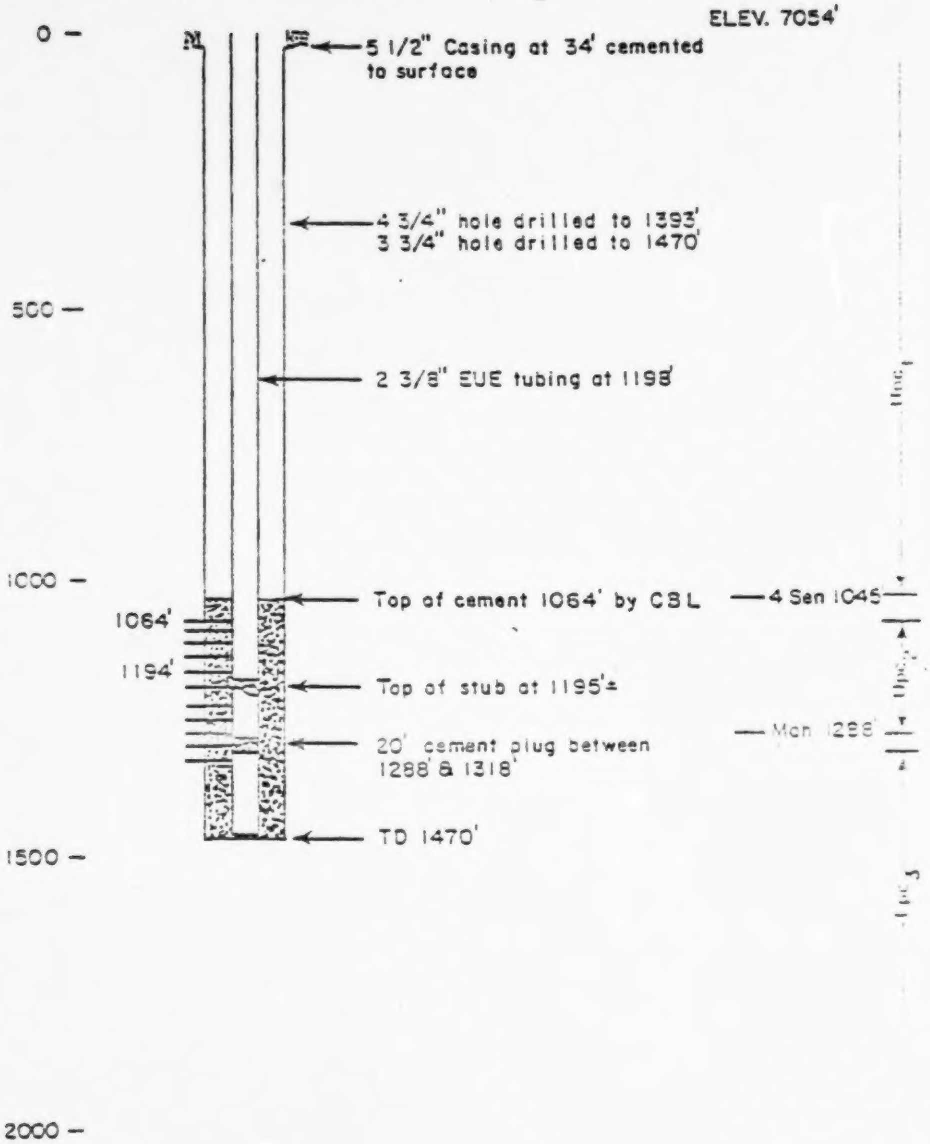


0-
500-
1000-
1500-
2000 -
ELEV. 6743'
5 1/2" Casing at 42' cemented to surface
4 3/4" hole drilled to 1989'
3 3/4" hole drilled to 2123'
12 Sack cement plug at 1002'
1128'
Top of cement 1130' by CBL
2 3/8" tubing cemented at 1458'±
1240'
Hole junked below 1541'
JUNK
TD 2123'
4 Sen 989'
Man. 1254'
RS 1758'
Upc1
Upc2
Lpc3
Lpc4

FINAL WELL CONFIGURATION

CS-4 WX04

FINAL STATUS: Upc$_2$ Monitor

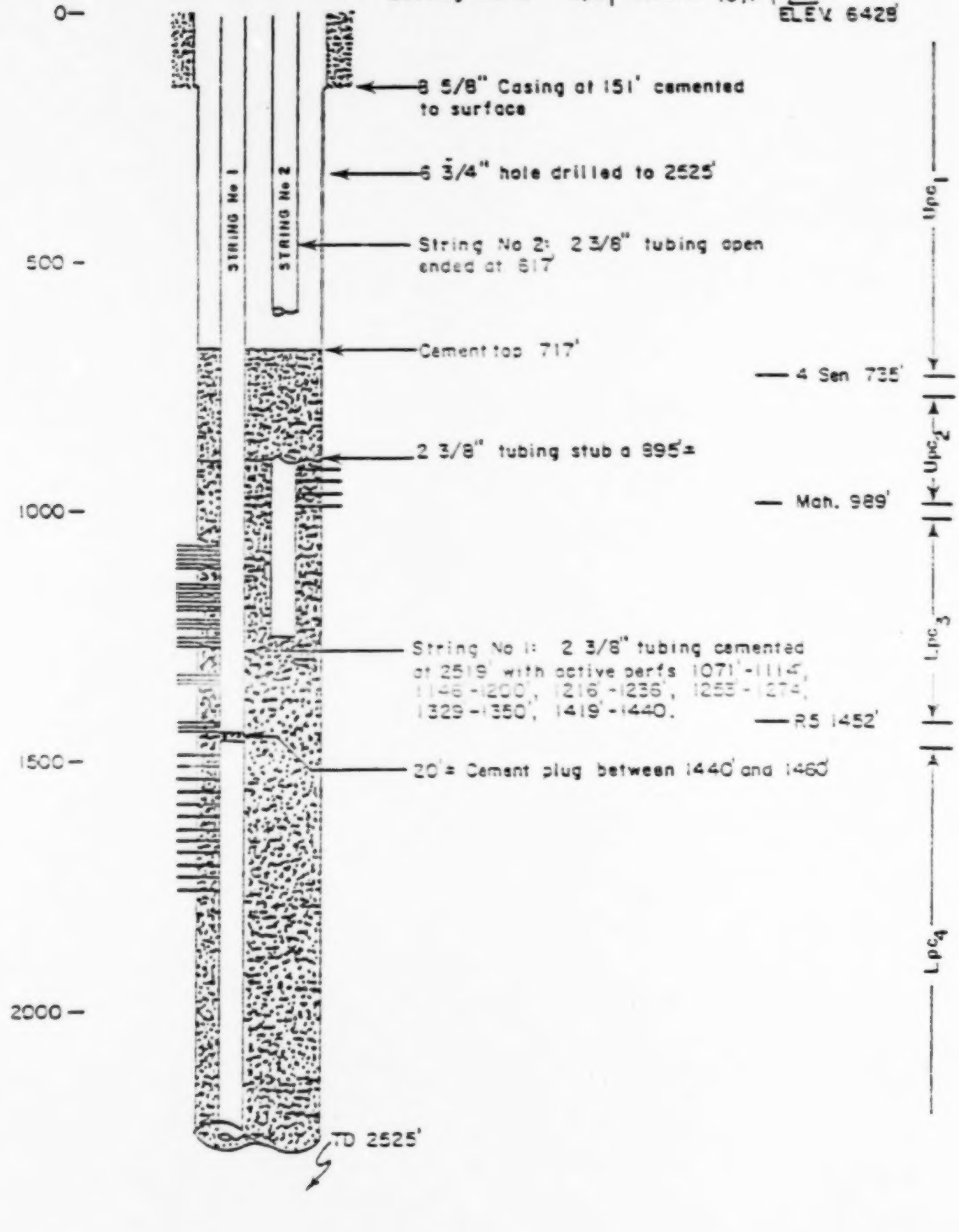

ELEV. 7054'
0 –
500 –
1000 –
1500 –
2000 –
5 1/2" Casing at 34' cemented to surface
4 3/4" hole drilled to 1393'
3 3/4" hole drilled to 1470'
2 3/8" EUE tubing at 1198'
Top of cement 1064' by CBL
1064'
1194'
Top of stub at 1195'±
20' cement plug between 1288' & 1318'
TD 1470'
4 Sen 1045
Mon 1288'
Upc1
Upc2
Upc3

APPENDIX V.4

FINAL WELL CONFIGURATION

SG-1

FINAL STATUS: String No 1 - Lpc_3 Monitor
String No 2 - Upc_1 Monitor ~X 12



8 5/8" Casing at 151' cemented to surface

6 3/4" hole drilled to 2525'

String No 2: 2 3/8" tubing open ended at 617'

Cement top 717'

4 Sen 735'

2 3/8" tubing stub @ 895'±

Man. 989'

String No 1: 2 3/8" tubing cemented at 2519' with active perfs 1071'-1114', 1146'-1200', 1216'-1236', 1253'-1274', 1329'-1350', 1419'-1440.

RS 1452'

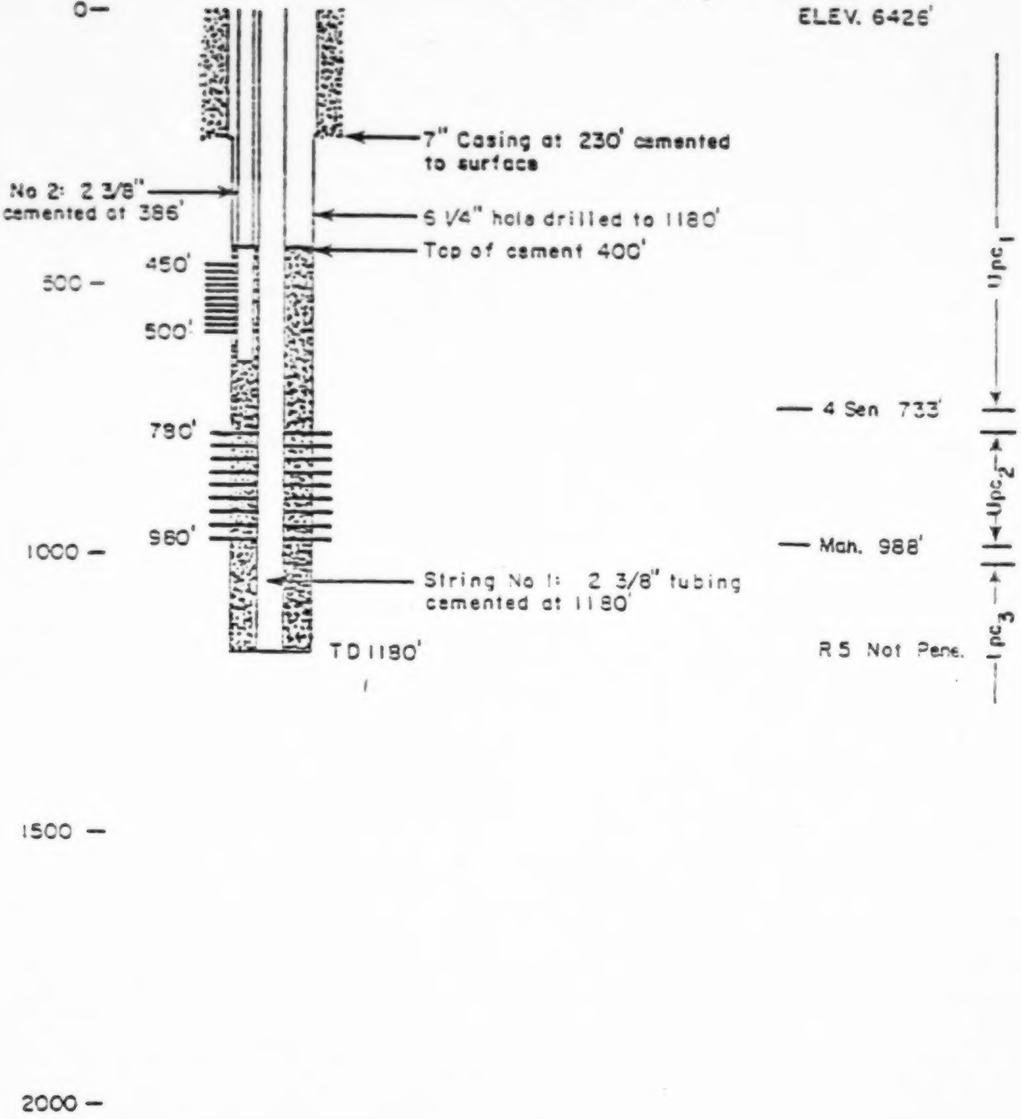
20'± Cement plug between 1440' and 1460'

APPENDIX V.5 614

FINAL WELL CONFIGURATION

SG-1A

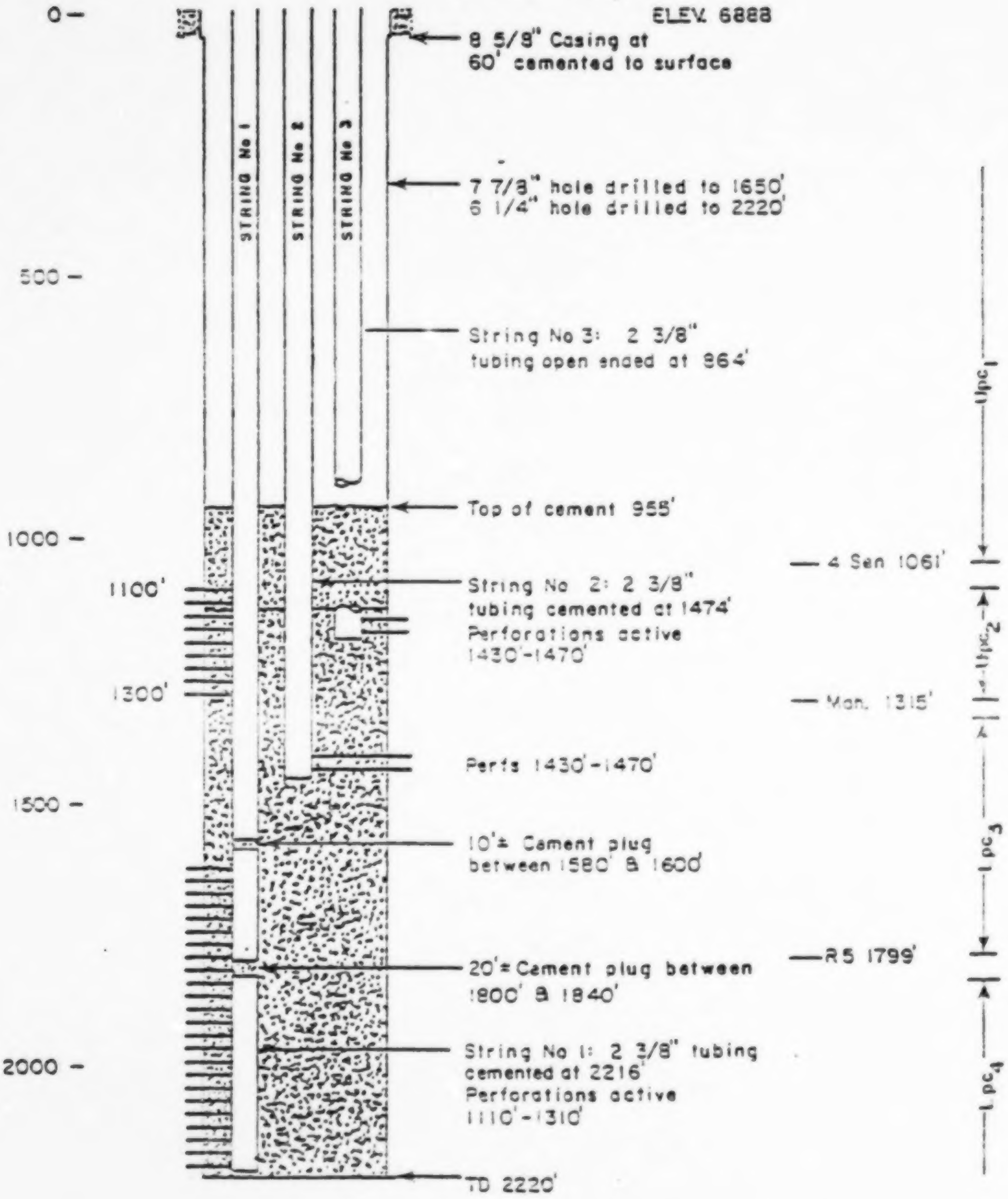
FINAL STATUS: String No 1 Upc_2 Monitor
String No 2 Upc_1 Monitor


ELEV. 6426'
0
500
1000
1500
2000
7" Casing at 230' cemented to surface
String No 2: 2 3/8" tubing cemented at 386'
6 1/4" hole drilled to 1180'
Top of cement 400'
450'
500'
780'
960'
String No 1: 2 3/8" tubing cemented at 1180'
TD 1180'
4 Sen 733'
Man. 988'
R 5 Not Pene.
Upc_1
Upc_2
Ipc_3

FINAL WELL CONFIGURATION

SG-6

FINAL STATUS: String No 1 - Upc_2 Monitor
String No 2 - Lpc_3 Monitor
String No 3 - Upc_1 Monitor

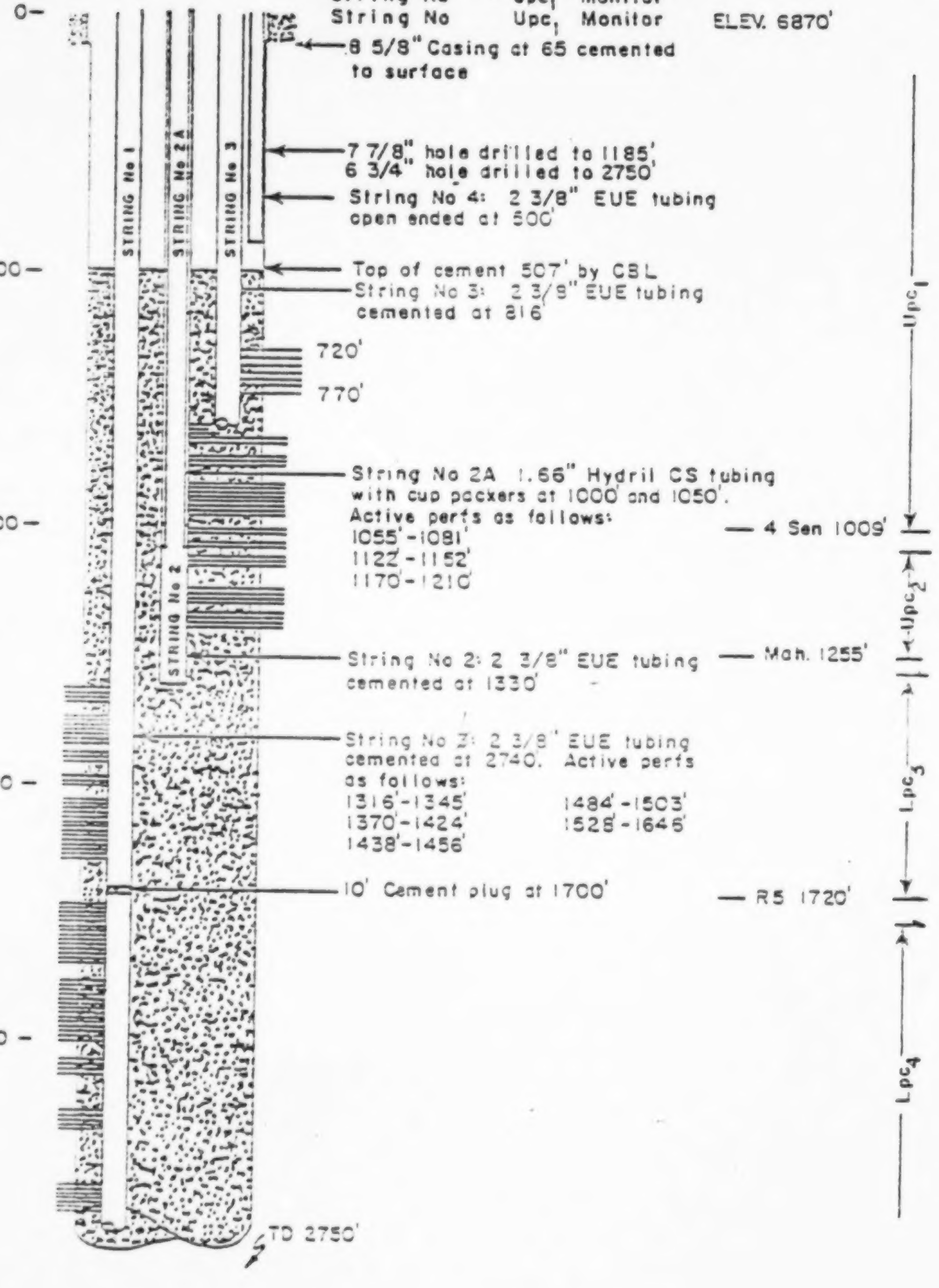


0 -
500 -
1000 -
1500 -
2000 -
1100'
1300'
ELEV. 6888
STRING No 1
STRING No 2
STRING No 3
8 5/8" Casing at 60' cemented to surface
7 7/8" hole drilled to 1650'
6 1/4" hole drilled to 2220'
String No 3: 2 3/8" tubing open ended at 864'
Top of cement 955'
String No 2: 2 3/8" tubing cemented at 1474' Perforations active 1430'-1470'
Perfs 1430'-1470'
10'± Cement plug between 1580' & 1600'
20'± Cement plug between 1800' & 1840'
String No 1: 2 3/8" tubing cemented at 2216' Perforations active 1110'-1310'
TD 2220'
4 Sen 1061'
Mon. 1315'
R5 1799'
Upc1
Upc2
Lpc3
Lpc4

FINAL WELL CONFIGURATION

SG-9

FINAL STATUS: String No 1 - Lpc_3 Monitor
String No 2A - Upc_2 Monitor
String No - Upc_1 Monitor
String No Upc_1 Monitor

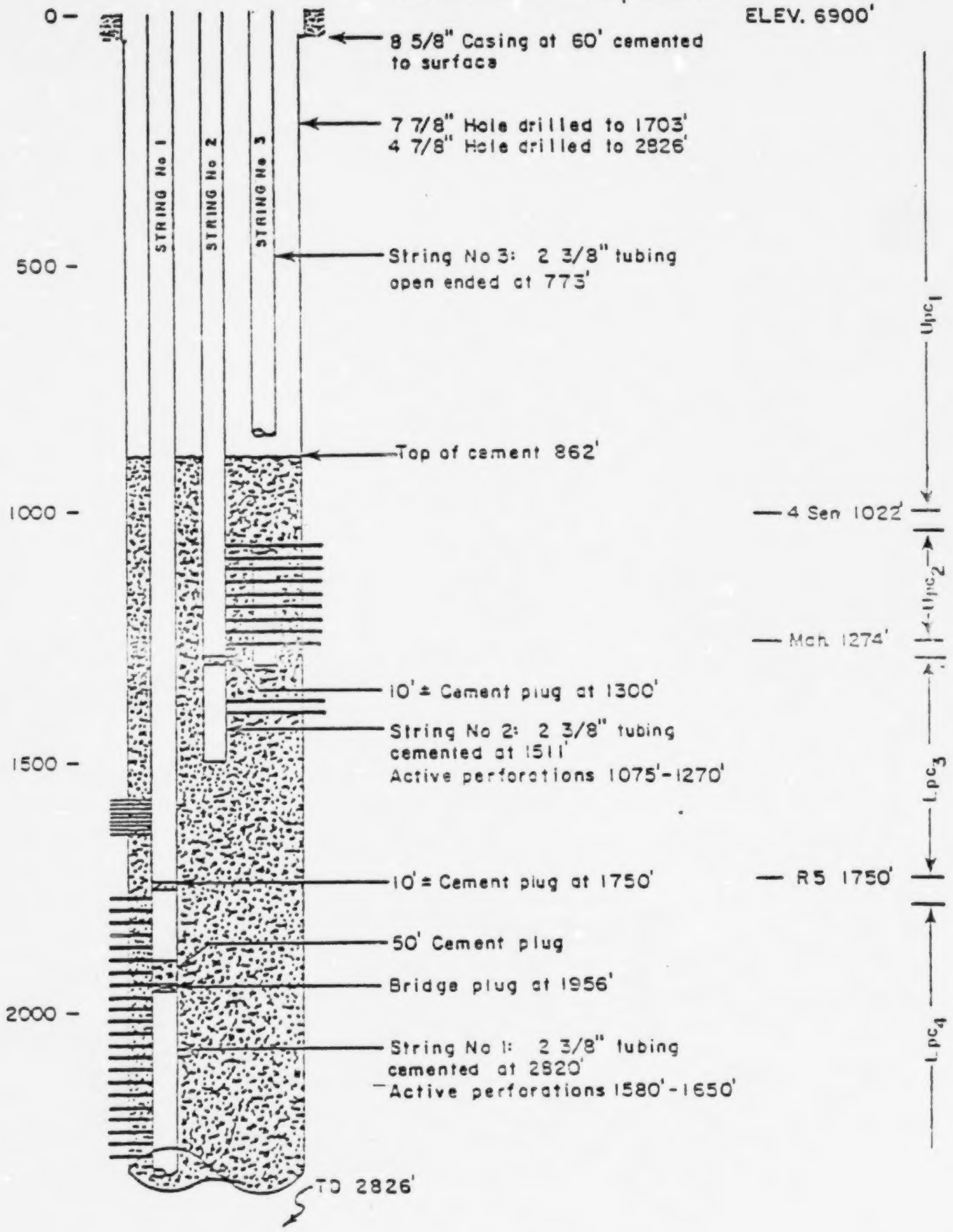

ELEV. 6870'
0 –
500 –
1000 –
1500 –
2000 –
STRING No 1
STRING No 2A
STRING No 3
STRING No 2
8 5/8" Casing at 65 cemented to surface
7 7/8" hole drilled to 1185'
6 3/4" hole drilled to 2750'
String No 4: 2 3/8" EUE tubing open ended at 500'
Top of cement 507' by CBL
String No 3: 2 3/8" EUE tubing cemented at 816'
720'
770'
String No 2A 1.66" Hydril CS tubing with cup packers at 1000' and 1050'. Active perfs as follows:
1055'-1081'
1122'-1152'
1170'-1210'
String No 2: 2 3/8" EUE tubing cemented at 1330'
String No 1: 2 3/8" EUE tubing cemented at 2740'. Active perfs as follows:
1316'-1345'
1370'-1424'
1438'-1456'
1484'-1503'
1528'-1646'
10' Cement plug at 1700'
TD 2750'
— 4 Sen 1009'
— Mah. 1255'
— R5 1720'
Upc_1
Upc_2
Lpc_3
Lpc_4

APPENDIX V.8

FINAL WELL CONFIGURATION

SG-11

FINAL STATUS: String No 1 - Lpc_3 Monitor
String No 2 - Upc_2 Monitor
String No 3 - Upc_1 Monitor



8 5/8" Casing at 60' cemented to surface

7 7/8" Hole drilled to 1703'
4 7/8" Hole drilled to 2826'

String No 3: 2 3/8" tubing open ended at 773'

Top of cement 862'

10' ± Cement plug at 1300'

String No 2: 2 3/8" tubing cemented at 1511'
Active perforations 1075'-1270'

10' ± Cement plug at 1750'

50' Cement plug

Bridge plug at 1956'

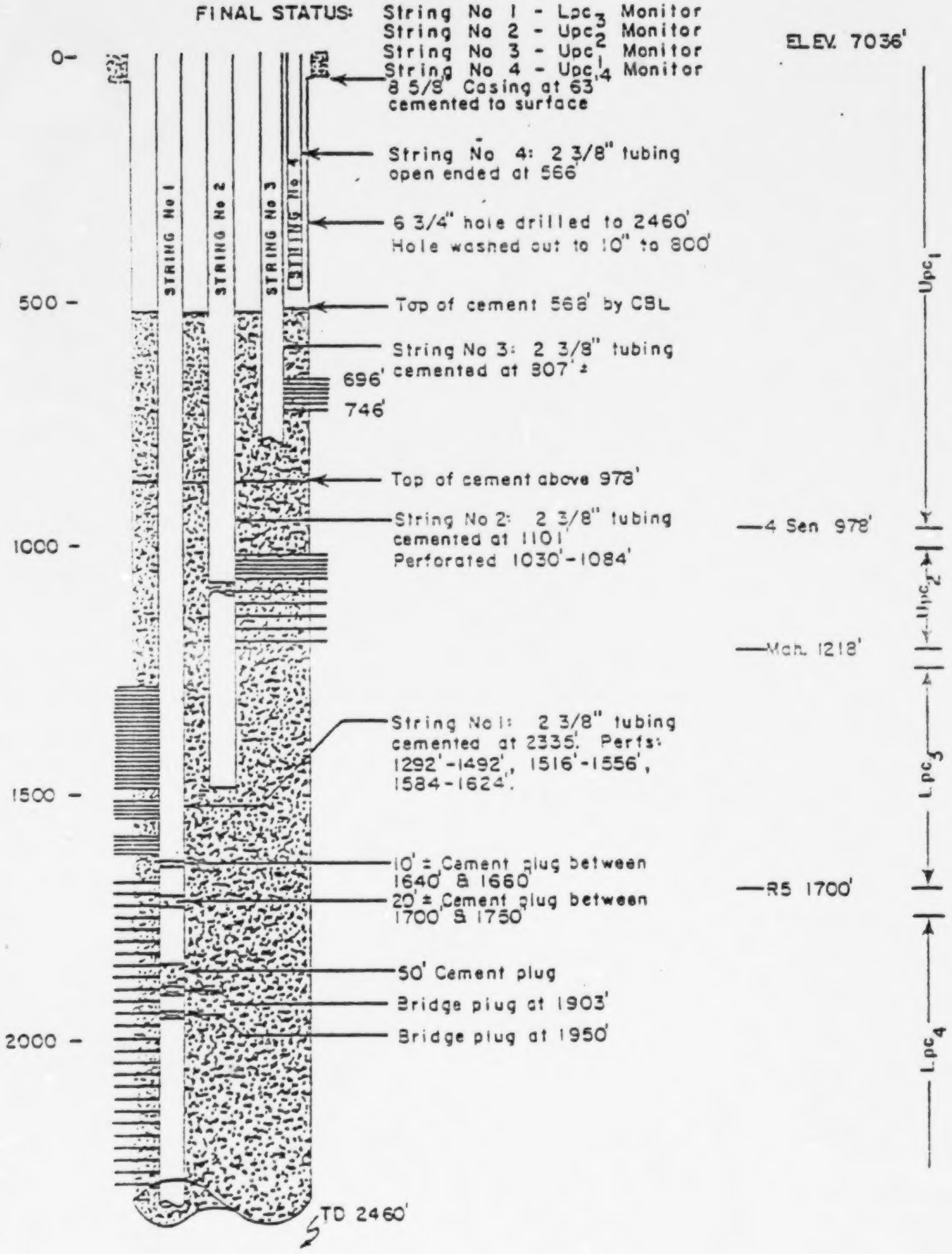
String No 1: 2 3/8" tubing cemented at 2820'
Active perforations 1580'-1650'

TD 2826'

APPENDIX V.9

FINAL WELL CONFIGURATION

SG-17


FINAL STATUS: String No 1 - Lpc3 Monitor
String No 2 - Upc2 Monitor
String No 3 - Upc1 Monitor
String No 4 - Upc4 Monitor
ELEV. 7036'
0-
500 -
1000 -
1500 -
2000 -
8 5/8" Casing at 63' cemented to surface
String No 4: 2 3/8" tubing open ended at 566'
6 3/4" hole drilled to 2460' Hole washed out to 10" to 800'
Top of cement 568' by CBL
String No 3: 2 3/8" tubing cemented at 807' ±
696'
746'
Top of cement above 978'
String No 2: 2 3/8" tubing cemented at 1101' Perforated 1030'-1084'
String No 1: 2 3/8" tubing cemented at 2335'. Perfs: 1292'-1492', 1516'-1556', 1584-1624'.
10' ± Cement plug between 1640' & 1660'
20' ± Cement plug between 1700' & 1750'
50' Cement plug
Bridge plug at 1903'
Bridge plug at 1950'
TD 2460'
STRING No 1
STRING No 2
STRING No 3
STRING No 4
—4 Sen 978'
—Mch. 1218'
—R5 1700'
Upc1
Upc2
Lpc5
Lpc4

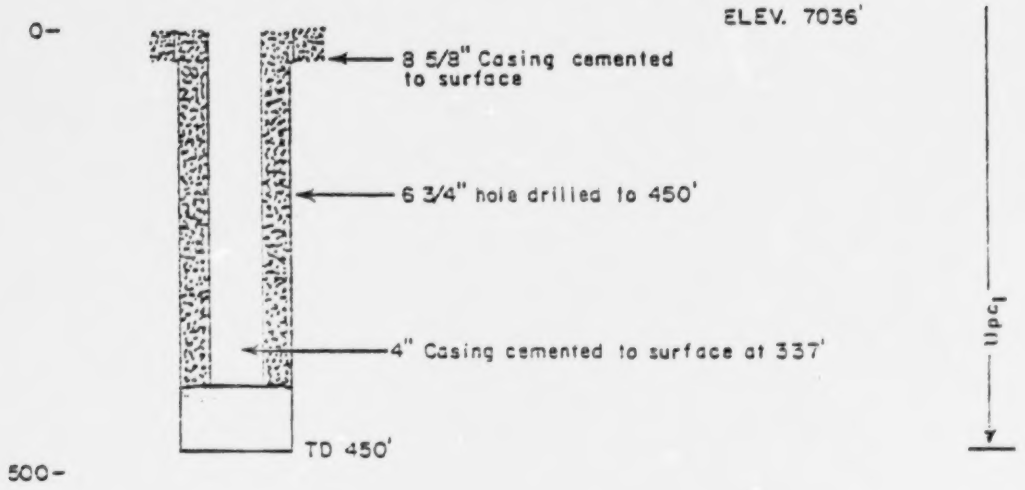
APPENDIX V.10

619

FINAL WELL CONFIGURATION

SG-17A

FINAL STATUS: Upc$_1$ Monitor



8 5/8" Casing cemented to surface

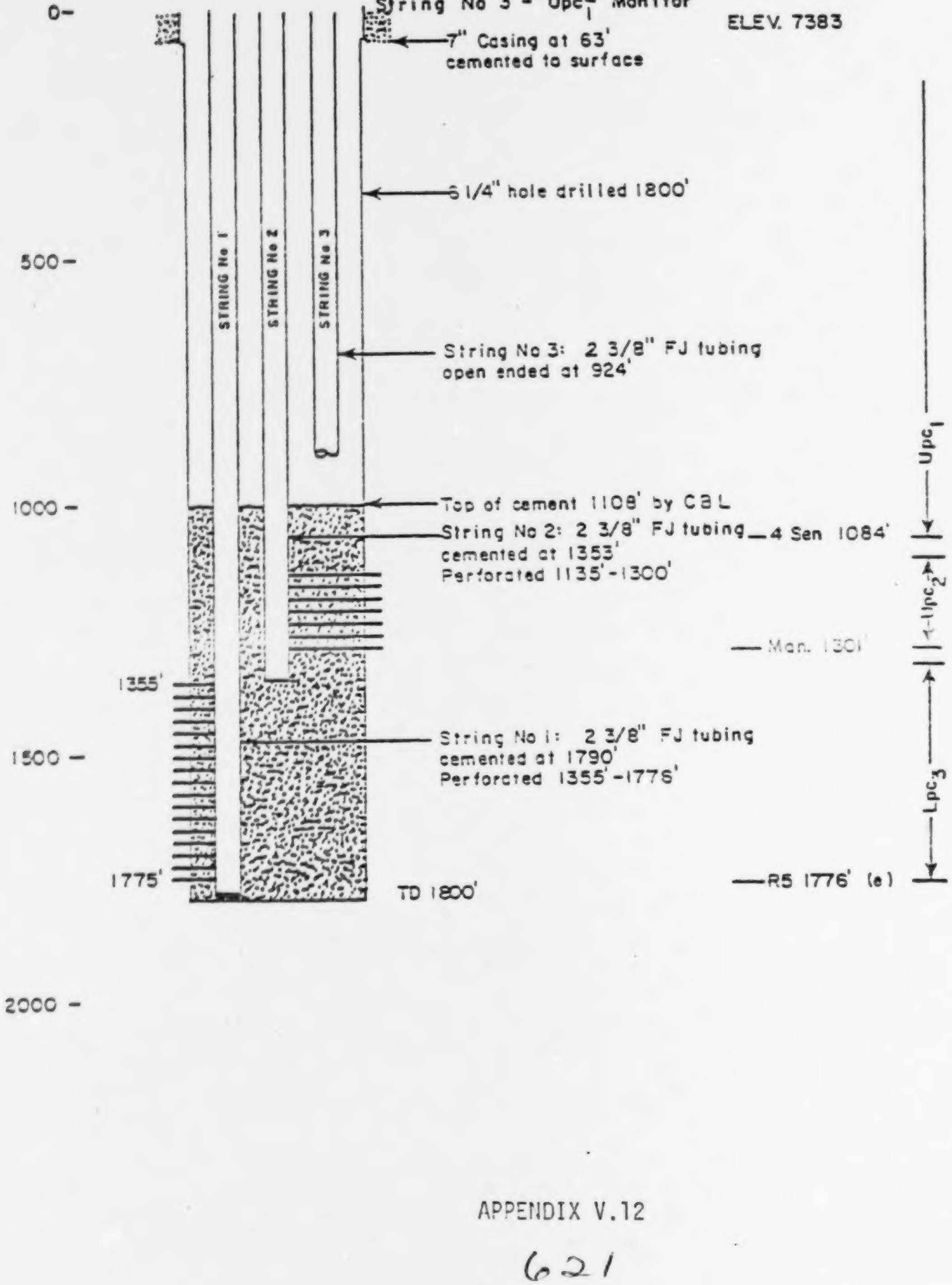
6 3/4" hole drilled to 450'

4" Casing cemented to surface at 337'

FINAL WELL CONFIGURATION

SG-18A

FINAL STATUS: String No 1 - Lpc_3 Monitor
String No 2 - Upc_2 Monitor
String No 3 - Upc_1 Monitor



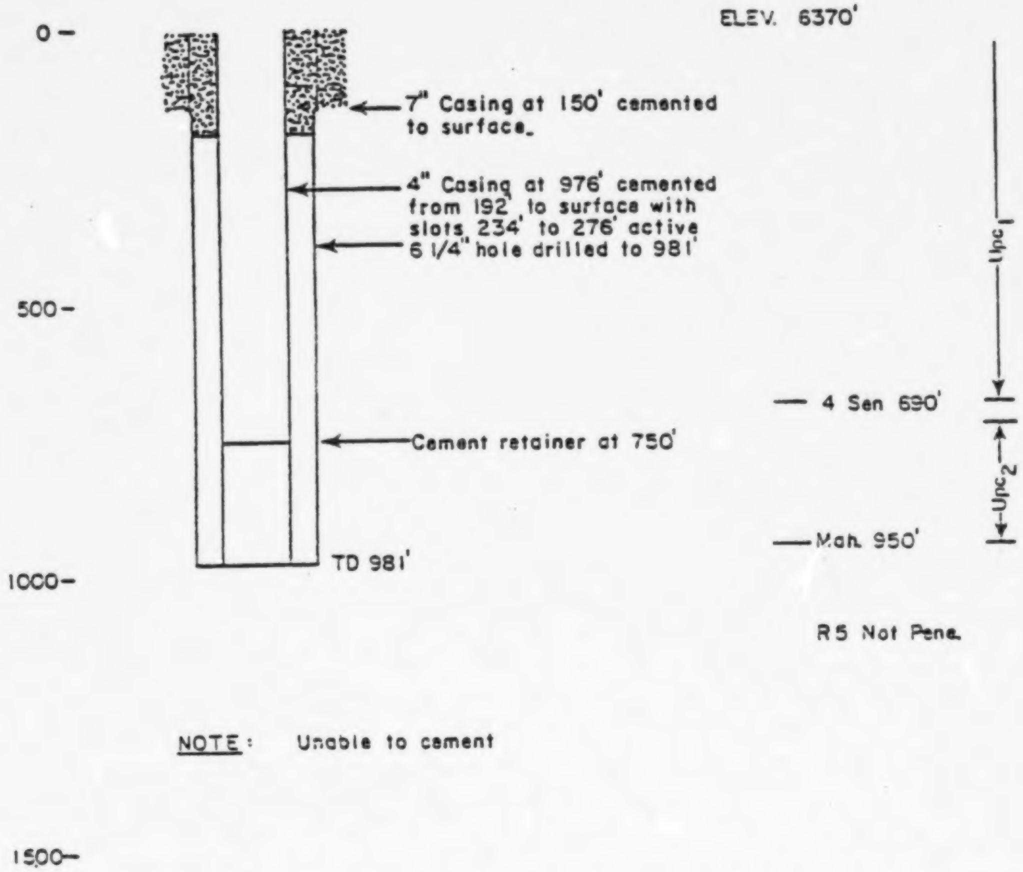
0-
ELEV. 7383
7" Casing at 63' cemented to surface
6 1/4" hole drilled 1800'
500-
STRING No 1
STRING No 2
STRING No 3
String No 3: 2 3/8" FJ tubing open ended at 924'
Upc1
1000-
Top of cement 1108' by CBL
String No 2: 2 3/8" FJ tubing cemented at 1353' Perforated 1135'-1300'
4 Sen 1084'
Upc2
Man. 1301
1355'
String No 1: 2 3/8" FJ tubing cemented at 1790' Perforated 1355'-1776'
1500-
Lpc3
1775'
TD 1800'
R5 1776' (e)
2000-

APPENDIX V.12

FINAL WELL CONFIGURATION

SG-19

FINAL STATUS: Inactive

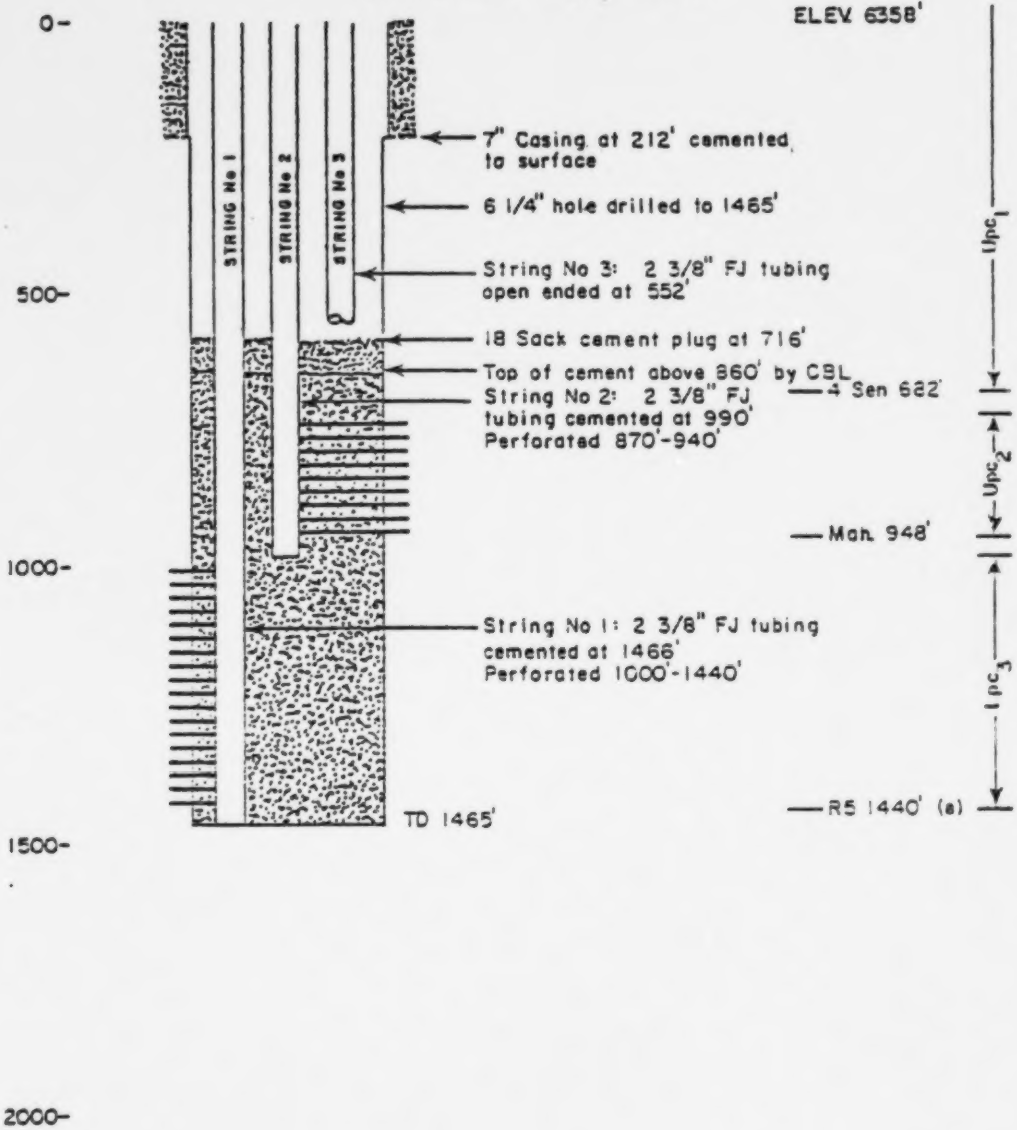

ELEV. 6370'
0 –
500 –
1000 –
1500 –
7" Casing at 150' cemented to surface.
4" Casing at 976' cemented from 192' to surface with slots 234' to 276' active
6 1/4" hole drilled to 981'
Cement retainer at 750'
TD 981'
Upc$_1$
4 Sen 690'
Upc$_2$
Mah. 950'
R5 Not Pene.

NOTE: Unable to cement

FINAL WELL CONFIGURATION

SG-20

FINAL STATUS: String No 1 - Lpc_3 Monitor
String No 2 - Upc_2 Monitor
String No 3 - Upc_1 Monitor

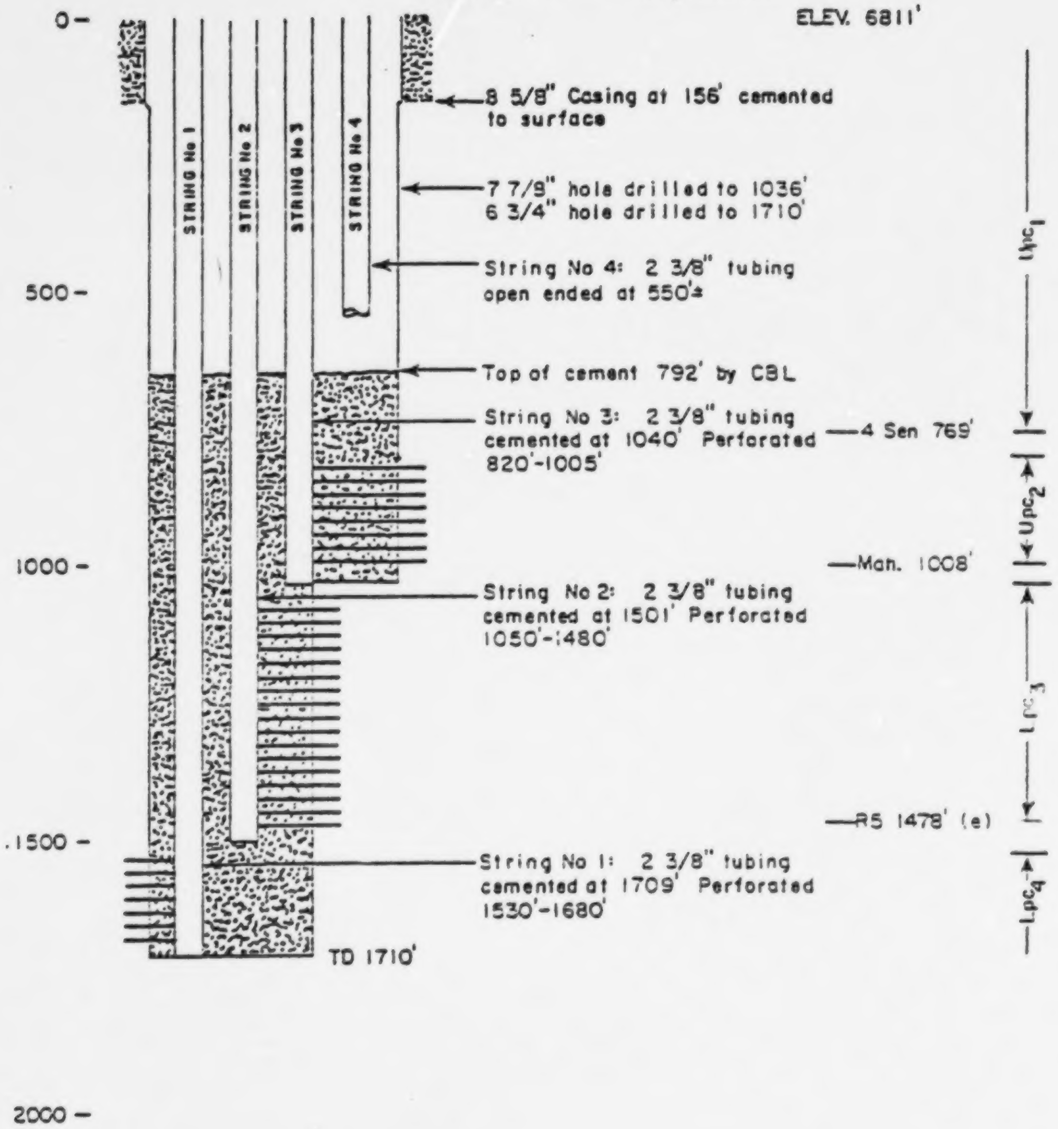


0-
500-
1000-
1500-
2000-
ELEV. 6358'
STRING No 1
STRING No 2
STRING No 3
7" Casing at 212' cemented to surface
6 1/4" hole drilled to 1465'
String No 3: 2 3/8" FJ tubing open ended at 552'
18 Sack cement plug at 716'
Top of cement above 860' by CBL
String No 2: 2 3/8" FJ tubing cemented at 990' Perforated 870'-940'
String No 1: 2 3/8" FJ tubing cemented at 1466' Perforated 1000'-1440'
TD 1465'
4 Sen 682'
Man. 948'
R5 1440' (a)
Upc1
Upc2
Lpc3

FINAL WELL CONFIGURATION

SG-21

FINAL STATUS: String No 1 - Lpc_4 Monitor
String No 2 - Lpc_3 Monitor
String No 3 - Upc_2 Monitor
String No 4 - Upc_1 Monitor

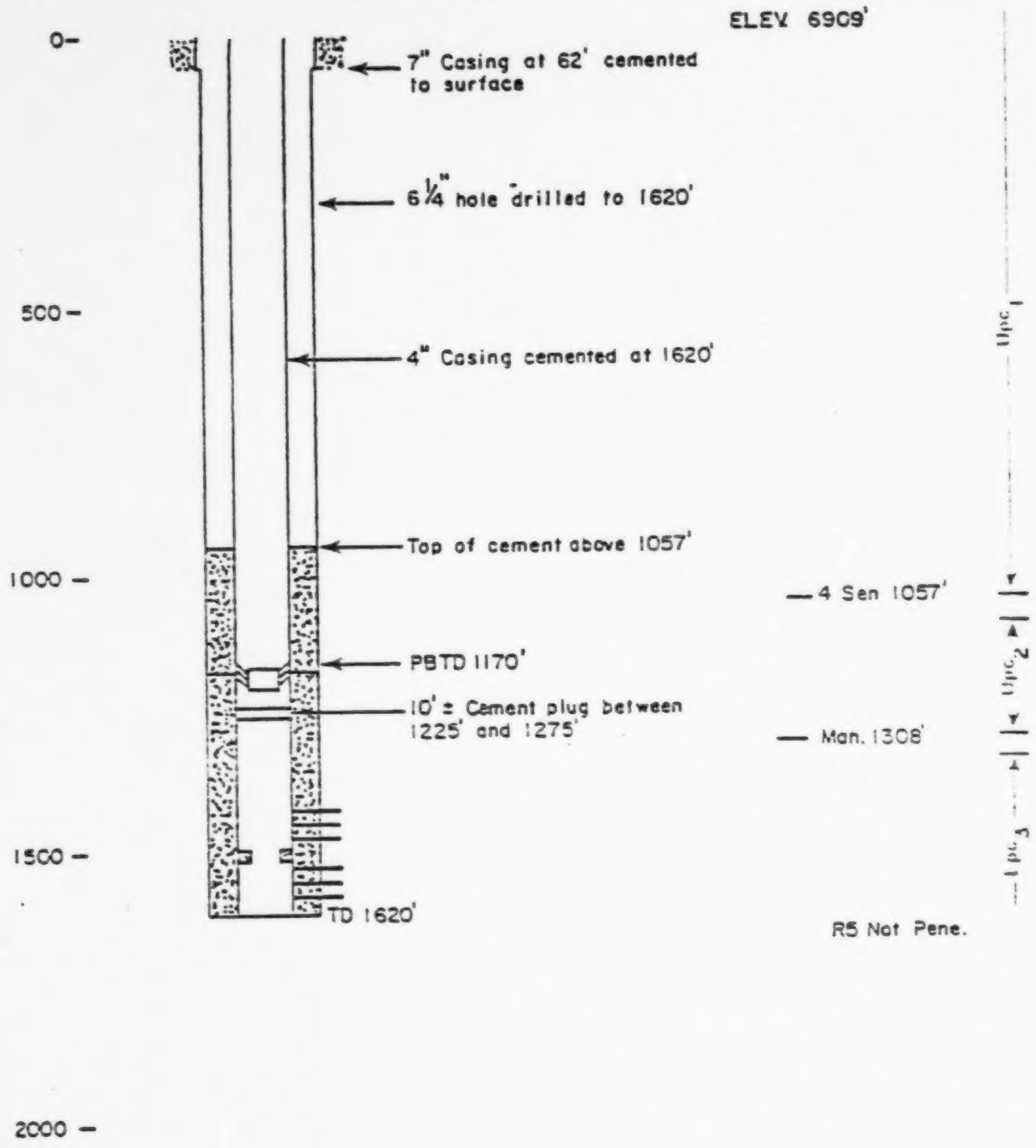

0 -
500 -
1000 -
1500 -
2000 -
ELEV. 6811'
STRING No 1
STRING No 2
STRING No 3
STRING No 4
8 5/8" Casing at 156' cemented to surface
7 7/8" hole drilled to 1036'
6 3/4" hole drilled to 1710'
String No 4: 2 3/8" tubing open ended at 550'±
Top of cement 792' by CBL
String No 3: 2 3/8" tubing cemented at 1040' Perforated 820'-1005'
String No 2: 2 3/8" tubing cemented at 1501' Perforated 1050'-1480'
String No 1: 2 3/8" tubing cemented at 1709' Perforated 1530'-1680'
TD 1710'
—4 Sen 769'
—Man. 1008'
—R5 1478' (e)
Upc1
Upc2
Lpc3
Lpc4

APPENDIX V.15

FINAL WELL CONFIGURATION

AT-1A

FINAL STATUS: Idle

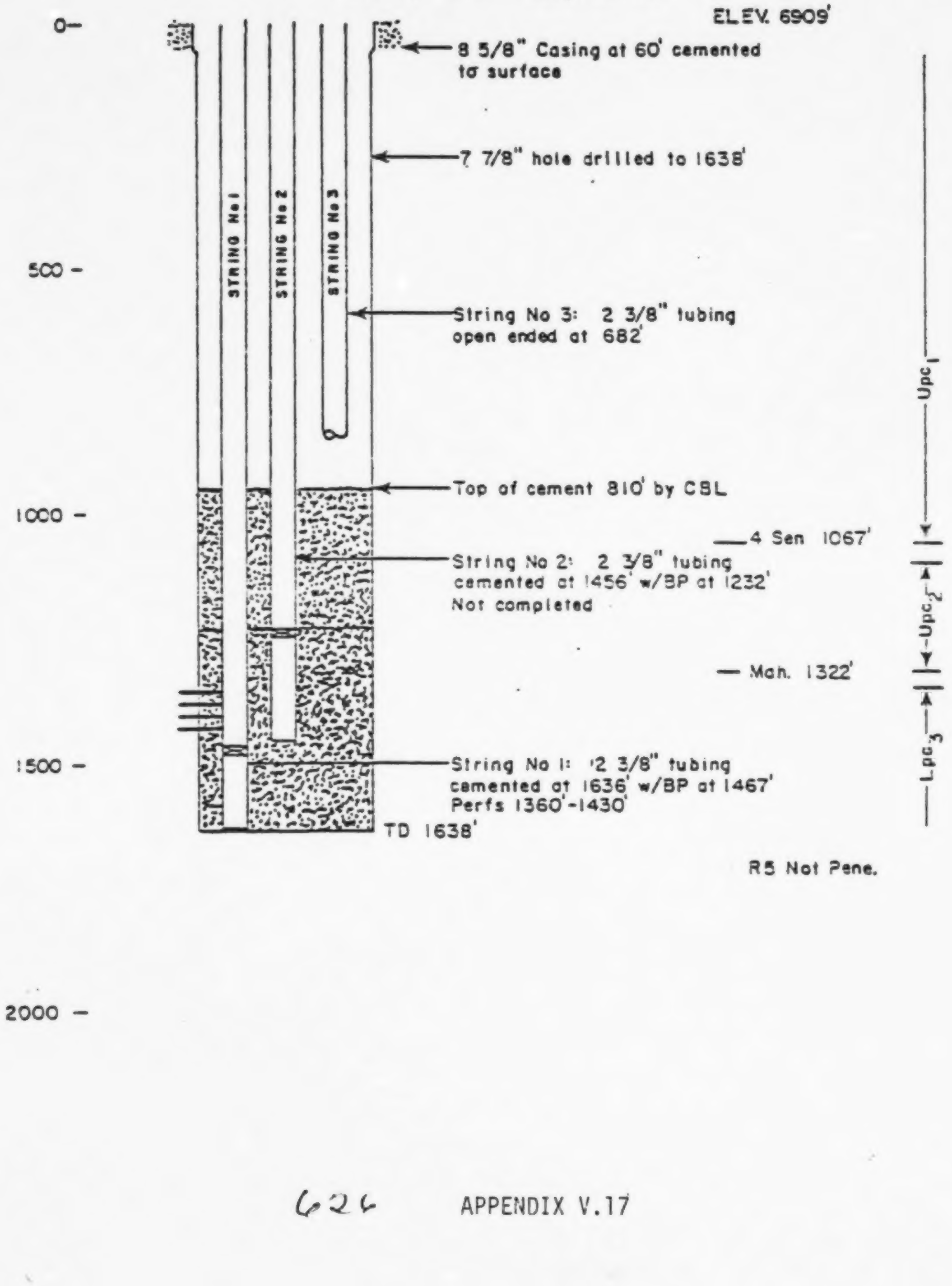

ELEV 6909'
0
500
1000
1500
2000
7" Casing at 62' cemented to surface
6 1/4" hole drilled to 1620'
4" Casing cemented at 1620'
Top of cement above 1057'
PBTD 1170'
10' ± Cement plug between 1225' and 1275'
TD 1620'
4 Sen 1057'
Man. 1308'
Upc1
Upc2
Upc3
R5 Not Pene.

625

FINAL WELL CONFIGURATION

AT-1B

FINAL STATUS: String No 1 - Lpc_3 Monitor
String No 2 - Abandoned
String No 3 - Upc_1 Monitor

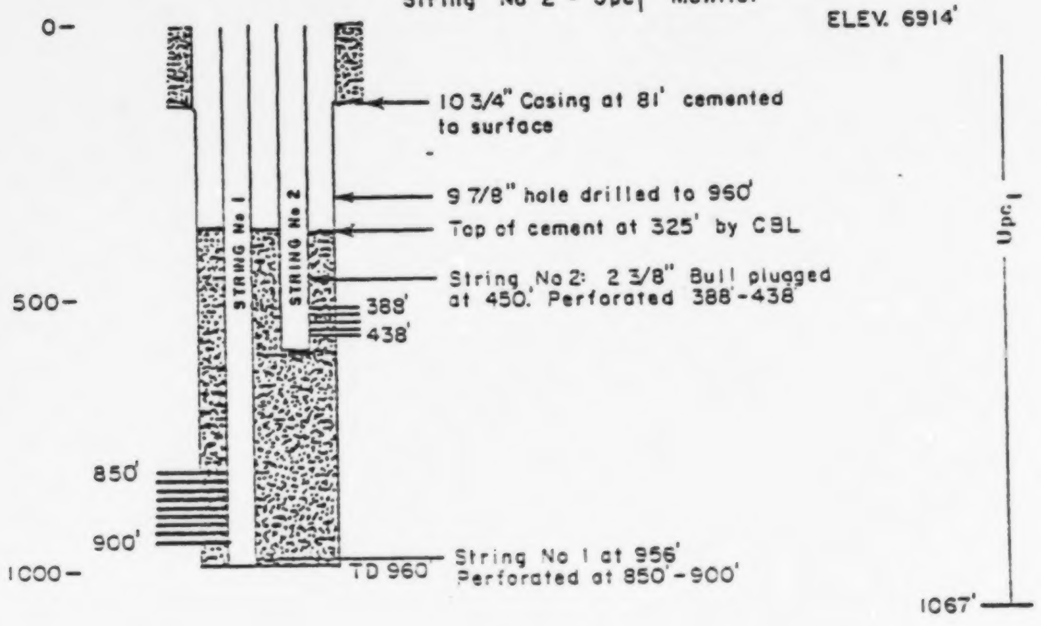


ELEV. 6909'
0 –
500 –
1000 –
1500 –
2000 –
8 5/8" Casing at 60' cemented to surface
7 7/8" hole drilled to 1638'
STRING No 1
STRING No 2
STRING No 3
String No 3: 2 3/8" tubing open ended at 682'
Top of cement 810' by CSL
4 Sen 1067'
String No 2: 2 3/8" tubing cemented at 1456' w/BP at 1232' Not completed
Mah. 1322'
String No 1: 2 3/8" tubing cemented at 1636' w/BP at 1467' Perfs 1360'-1430'
TD 1638'
R5 Not Pene.
Upc_1
Upc_2
Lpc_3

FINAL WELL CONFIGURATION

14 X 7

FINAL STATUS: String No 1 - Upc_1 Monitor
String No 2 - Upc_1 Monitor


ELEV. 6914'
0-
500-
1000-
STRING No 1
STRING No 2
10 3/4" Casing at 81' cemented to surface
9 7/8" hole drilled to 960'
Top of cement at 325' by CBL
String No 2: 2 3/8" Bull plugged at 450.' Perforated 388'-438'
388'
438'
850'
900'
TD 960'
String No 1 at 956' Perforated at 850'-900'
Upc1
1067'

APPENDIX VI

WATER QUALITY PARAMETERS - UPPER AQUIFER

Well	Conductance	pH	Total Dissolved Solids	P Alkalinity	MO Alkalinity	Hardness	Gross Alpha Radiation	Gross Beta Radiation	Total Organic Carbon
eb-2	1600	8.9	1000	--	--	39	2	0	<1
	1600	8.7	1000	60	360	24	12	0	4
	1600	9.1	980	39	400	48	3	0	<1
	1583	8.9	1025	--	--	--	7.8	0	--
b-4 eb-4	800	8.4	520	--	--	180	1	0	<1
	800	8.7	550	10	320	170	16	0	3
	800	8.8	540	15	390	190	5	0	1
	890	8.6	557	--	--	--	0	2	--
AT-1c, String 3	1200	8.6	750	--	--	150	2	2	<1
	1200	8.5	880	<.1	660	300	8	0	1
	1400	8.5	920	20	360	340	1	0	<3
	1400	8.4	935	--	--	--	--	--	--
	1595	8.6	955	--	--	--	11	0	--
SG-1, String 2	1200	8.7	890	10	500	270	8	0	<1
	1200	8.7	800	22	440	60	6	0	<1
	1000	8.3	840	--	--	--	--	--	--
	1347	8.6	834	--	--	--	3.9	8	--
SG-6, String 3	1500	8.3	1200	10	370	560	1	0	9
	1600	8.4	1000	15	320	630	3	0	4
	1500	8.3	1129	--	--	--	4.7	2	--
	1584	8.7	--	--	--	--	4.2	7	--
SG-8, String 2	2100	8.8	1400	30	990	180	11	0	3
	1900	8.8	1100	64	810	190	7	0	4
SG-9, String 2	1600	8.5	1300	--	--	570	2	2	8
	2000	8.1	1400	<.1	560	640	8	0	5
	1800	8.4	1300	--	540	720	2	0	<1
	1500	8.1	1391	--	--	--	--	--	--
	1822	8.3	1318	--	--	--	.7	0	--
SG-10A	1300	8.6	940	10	360	370	6	0	<1
	1300	8.4	840	5	320	380	6	0	<1
	1458	8.3	905				10	4	--
SG-11, String 3	1600	8.9	1200	39	600	340	7	0	3
	2000	8.7	1300	39	820	280	1	0	8
	1890	8.4	1164	--	--	--	8	31	--
SG-17, String 2	4200	8.8	3100	98	1500	84	21	0	4
	2500	9.0	1100	34	740	72	4	0	3
	1200	8.8	749	--	--	--	--	--	--
	1661	8.9	941	--	--	--	2.4	0	--
SG-18A	--	8.2	540	--	--	--	8	3	<1
	900	8.7	620	10	390	240	4	0	<1
	800	8.8	520	15	360	190	0	0	<1
	1019	8.8	597	--	--	--	4.9	7	--
SG-19	2800	8.4	1800	--	--	29	8	33	<1
	2800	8.6	1800	45	430	36	20	0	7
	2600	9.0	1800	44	1400	32	6	0	3
	2864	8.8	1741	--	--	--	0	0	--
SG-20	2800	8.7	1900	70	1500	32	12	0	8
	2600	9.0	1700	49	1400	32	6	0	3
	2500	8.4	1745	--	--	--	4	32	--
	2845	8.8	1715	--	--	--	2.2	0	--
SG-21	1000	8.5	590	20	380	160	9	0	2
	900	8.9	540	10	380	140	3	0	<1
	1055	8.7	612	--	--	--	1.6	16	--

MAJOR CONSTITUENTS - UPPER AQUIFER

Well	Mg	NO_3	PO_4	K	Na	SiO_2	SO_4
Cb-2	4	0.3	<.1	3	380	17	330
	3	1.2	<.1	6	350	19	300
	4	0.3	<.1	3	370	15	320
	4	.36	<.02	2	367	15	325
Cb-4	23	0.2	<.1	<1	130	23	140
	25	0.4	0.1	1	150	32	130
	27	0.8	<.1	1	140	20	140
	26	.06	<.02	.7	140	25	142
AT-1c, String 3	23	<.1	<.1	4	220	18	230
	45	0.5	<.1	4	230	13	300
	54	1.5	<.1	1	210	19	370
	50	.04	.04	2.6	200	19	370
	45	<.02	<.01	2	228	19	372
SG-1, String 2	43	<.1	<.1	1	230	21	240
	56	0.2	<.1	1	220	19	200
	48	.04	.02	.5	200	17	234
	53	.10	<.02	.7	204	20	239
SG-6, String 3	99	0.5	<.1	1	180	15	520
	120	0.2	<.1	1	180	20	350
	88	.82	.07	.8	178	15	510
	90	.02	.02	.9	181	9	306
SG-8, String 2	27	0.4	<.1	2	510	16	120
	25	0.4	<.1	1	430	13	[illegible]
SG-9, String 2	100	0.4	<.1	5	270	20	430
	150	0.4	0.4	5	220	22	520
	140	0.2	<.1	5	210	23	[illegible]
	129	.04	<.02	2.9	200	23	[illegible]
	133	.08	<.02	2	195	30	[illegible]
SG-10A	50	<.1	<.1	1	180	24	380
	53	0.1	<.1	1	190	21	360
	58	.03	.02	.7	186	25	410
SG-11, String 3	70	<.1	<.1	5	350	4	260
	51	0.3	0.1	11	410	14	140
	57	.12	.04	5	348	17	152
SG-17, String 2	7	1.9	<.1	9	1200	28	99
	8	0.2	<.1	3	44	13	35
	2.2			3	296	7.5	91
	3	.06	.03	1.7	330	13	21
SG-18A	30	0.2	--	<1	140	23	84
	37	0.1	0.2	1	150	21	130
	29	0.2	<.1	1	150	19	77
	35	<.04	<.02	.3	148	26	131
SG-19	3	<.1	<.1	--	760	9	<4
	3	<.1	<.1	1	780	9	23
	3	0.2	<.1	1	910	7	<4
	3	.03	.03	.9	760	13	4
SG-20	3	0.9	<.1	1	770	7	27
	3	2.1	<.1	1	760	7	<4
	2.9	.38	.15	.8	752	9	<4
	3	2.9	.03	.9	737	11	5
SG-21	25	0.6	0.2	1	190	15	80
	20	0.6	<.1	1	180	14	79
	24	.08	<.02	.3	183	17	14

MAJOR CONSTITUENTS - UPPER AQUIFER

Well	NH_3	HCO_3	Ca	CO_3	Cl	OH	Li
Cb-2	0.5	500	6	24	10	<.1	<.5
	0.5	550	3	46	11	<.1	<.5
	0.6	500	5	22	11	<.1	<.5
	.19	558	6	18	12	--	<.5
Cb-4	0.4	350	22	5	2	<.1	<.5
	0.4	400	23	8	7	<.1	<.5
	0.6	340	20	10	7	<.1	<.5
	.14	344	24	22	6	--	<.5
AT-1c String 3	0.2	450	15	9	7	<.1	<.5
	1.1	460	44	9	6	<.1	<.5
	0.8	410	51	7	7	<.1	<.5
	1.8	451	52	3.3	9	--	--
	.22	478	30	8	10	--	<.5
SG-1 String 2	0.5	580	29	24	18	<.1	<.5
	0.4	510	30	12	9	<.1	<.5
	1.5	573	41	3	8	--	<.5
	.37	539	27	11	8	--	<.5
SG-6 String 3	1.8	440	74	6	49	<.1	<.5
	0.8	440	78	6	29	<.1	<.5
	2.4	461	72	4.2	27	--	<.5
	.28	407	55	10	30	--	<.5
SG-8 String 2	1.6	1300	20	42	38	<.1	<.5
	0.9	1100	18	30	13	<.1	<.5
SG-9 String 2	0.2	740	117	12	49	<.1	<.5
	0.8	820	84	<1	22	<.1	<.5
	0.5	640	77	6	19	<.1	<.5
	1.1	793	100	--	19	--	<.5
	.32	677	92	6	17	--	<.5
SG-10A	1.7	440	57	12	13	<.1	<.5
	0.8	400	58	3	8	<.1	<.5
	.16	357	37	7	4	--	<.5
SG-11 String 3	0.7	820	16	36	53	<.1	<.5
	2.0	1100	23	24	46	<.1	<.5
	2.48	1010	43	11	19	--	<.5
SG-17 String 2	7.9	2100	7	60	514	<.1	3.1
	1.9	890	21	32	77	<.1	<.5
		604	4	15	19	--	<.5
	.43	883	9	28	20	--	<.5
SG-18A	--	470	24	--	3	--	0.3
	1.0	460	29	18	4	<.1	<.5
	0.6	420	19	11	3.	<.1	<.5
	3.1	411	26	17	4	--	<.5
SG-19	0.1	1800	7	66	10	<.1	<.5
	1.1	2000	5	24	11	<.1	<.5
	1.5	1600	5	76	14	<.1	<.5
	1.2	1780	5	42	12	--	<.5
SG-20	1.4	2000	4	32	13	<.1	<.5
	1.0	1600	4	74	13	<.1	<.5
	4.1	1870	5.6	20	12	--	<.5
	.6	1780	5	42	12	--	<.5
SG-21	0.4	500	19	9	2	<.1	<.5
	0.4	420	16	16	2	<.1	<.5
	3.0	465	20	11	4	--	<.5

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IMPORTANT TRACE ELEMENTS - UPPER AQUIFER

Well	Al	As	Ba	Be	B	Cd	Cr	Co	Cu
Cb-2, Fall '74	--	.02	.04	<.001	2.9	ND	.3	.002	3
Spring '75	--	.02	.1	ND	.1	.004	<.01	.008	.05
Fall '75	.3	.005	.02	ND	1.6	ND	<.01	<.001	.004
	.03	.005	.03	ND	.1	ND	.02	.002	.02
CB-4	--	.01	.02	<.001	2.3	ND	.03	.002	.5
	.3	.02	.2	ND	.4	.008	<.01	.006	.09
	.5	.005	.03	ND	<.1	<.01	<.01	<.001	.007
	.04	.005	.1	ND	.07	ND	<.01	<.001	.02
AT-1c, String 3	[illegible]	.06	.02	ND	1.3	ND	.006	.002	.03
	.08	.02	.06	<.001	.16	ND	<.01	ND	.02
	.07	.04	.05	ND	.3	ND	<.01	ND	.005
		.013							
	.02	.004	.08	ND	.2	<.01	.02	<.005	.02
SG-1, String 2	[illegible]	.03	.04	<.002	.42	ND	<.01	<.002	.05
	[illegible]	.004	.02	ND	.8	ND	<.01	ND	.04
	.02	.006	.02	ND	.03	ND	.007	<.003	.01
	.02	.009	.06	ND	.3	<.02	.004	.002	.01
SG-8, String 2	.04	.03	.6	ND	1.9	ND	<.01	<.001	.01
	.4	.02	.1	<.001	1.0	<.003	<.01	<.001	.01
SG-9, String 2	[illegible]	.009	.07	.003	1.5	ND	<.01	.01	.03
	.05	.01	.1	ND	0.4	ND	<.01	.003	.05
	[illegible]	.003	.03	ND	1.0	ND	<.01	<.002	.03
	.007	.005	.01	<.001	.04	ND	.01	.002	.01
	[illegible]	.020	.03	ND	.07	<.01	.02	<.007	.01
SG-6, String 3	[illegible]	.009	.06	ND	.35	ND	<.01	<.001	.03
	.005	.004	.02	ND	.6	ND	<.01	.001	.003
	[illegible]	.001	.2	ND	.05	ND	.03	<.003	.003
	.04	.005	.05	ND	.02	ND	.006	<.005	.04
SG-11, String 3	[illegible]	.02	ND	ND	1.5	ND	<.01	<.004	.009
	[illegible]	.006	.03	ND	1.9	ND	<.01	<.001	.007
	[illegible]	.050	.2	<.001	.6	<.01	.01	<.006	.02
SG-10A	[illegible]	.006	.02	ND	3.2	ND	<.01	<.002	.005
	[illegible]	.03	.04	ND	.3	ND	<.01	.003	.03
	[illegible]	.006	.04	ND	.01	ND	.01	<.006	.01
SG-17, String 2	[illegible]	.03	.1	ND	18.	ND	<.01	<.003	.01
	[illegible]	.02	.3	ND	6.2	ND	<.01	<.001	.007
	[illegible]	.02	.06	ND	.2	ND	<.02	<.001	.02
	[illegible]	.008	.1	<.001	.3	ND	.007	<.004	.007
SG-18A	[illegible]	.02	.03	ND	1.4	ND	--	.001	.02
	.03	.006	.04	ND	.70	ND	<.01	<.002	.01
	[illegible]	.006	.04	ND	.7	ND	<.01	<.008	.01
	.04	.003	.05	ND	.1	ND	.01	<.009	.02
SG-19	--	<.001	.2	ND	2.0	ND	.002	<.001	.08
	.05	.002	.2	ND	1.6	ND	<.01	<.002	.05
	[illegible]	.001	.1	ND	1.4	ND	<.01	<.002	.01
	.003	.001	.3	<.001	.2	ND	.002	<.002	.008
SG-20	[illegible]	.004	.3	ND	1.6	ND	<.01	<.004	.03
	[illegible]	.004	.3	<.001	2.2	ND	<.01	ND	.02
	[illegible]	.003	.2	<.001	.4	ND	--	<.003	.02
	[illegible]	<.002	.4	<.001	3.	ND	.005	<.01	.03
SG-22	[illegible]	.006	.1	ND	0.4	ND	<.01	<.003	.005
	[illegible]	.008	.009	<.001	.2	ND	<.01	<.002	.01
	[illegible]	.008	.09	ND	.4	<.01	.009	<.008	.01

IMPORTANT TRACE ELEMENTS - UPPER AQUIFER

Well	F	Fe	Pb	Mn	Hg	Ni	Se	V	Zn
SG-2	2.9	.5	.02	.1	--	.02	ND	.002	.4
	4.0	1.2	.07	.1	.0004	.2	.002	.003	.1
	.9	.2	<.002	.01	<.0001	.003	ND	<.001	.003
	1.8	.3	.007	<.1	.00013	.01	.005	<.001	.01
SG-4	1.0	.3	<.01	.1	--	.02	ND	.001	.07
	.9	<.05	.02	.02	.0002	.08	ND	.001	1.0
	.3	.07	.02	.04	<.0001	.02	.001	<.001	.04
	.6	<.1	<.02	<.1	.00012	.006	<.007	.001	.03
AT-1c, String 3	6.4	.28	.01	.2	.0008	.01	ND	.001	.03
	4.0	<.05	.01	.04	.0002	<.001	<.004	<.001	.07
	4.0	.1	.01	.02	<.0001	.007	<.001	<.001	.04
	3.1	1.1		.2	--				
	4.3	<.1	<.01	.1	.00007	.008	.002	.001	.03
SG-1, String 2	3.0	<.05	.02	.03	.0004	.02	.004	.003	.1
	3.3	.2	.003	.04	<.0001	.003	<.002	<.001	.01
	3.2	.1	.05	<.1	<.00003	.01	ND	.002	.02
	3.	<.1	.007	<.1	.0023	.01	.01	<.001	.07
SG-8, String 2	15.	<.05	.01	.04	.0002	.02	.02	.001	1.0
	13.	.6	.006	.009	<.0001	.01	.001	.001	.02
SG-9, String 2	.2	.18	<.02	.4	--	.02	.009	.004	.1
	1.3	<.05	.02	.1	.0001	.04	.001	<.001	1.0
	1.2	1.3	.01	.6	.0003	.007	ND	<.002	.06
	.7	1.8	<.01	.3	.0001	.01	ND	<.001	.03
	2.4	7.	.01	.3	.00009	.03	.03	<.001	.03
SG-6, String 3	.3	.44	.007	.2	.0029	.02	<.004	.002	.7
	.1	.2	.003	.1	<.0001	.004	<.001	.001	.04
	.2	.1	<.02	.2	<.00003	.009	ND	.001	.02
	2.0	<.1	<.01	.3	.00009	.009	<.01	<.001	.02
SG-11, String 3	4.4	<.05	.01	.02	.0002	.006	.003	<.001	.4
	7.3	<.05	.01	.3	.0002	.005	ND	<.001	.01
	6.	6.	.01	.1	.0001	.01	<.006	<.001	.03
SG-10A	.41	.08	.01	.03	.0001	.01	.007	<.002	.3
	.5	1.1	.01	.06	.0002	.009	.02	.006	.06
	.4	.1	.01	.1	.00012	.01	<.004	<.001	.03
SG-17, String 2	17.	<.05	.02	.01	.0031	.01	.007	.006	2.
	16.	.09	.01	.03	.0009	.006	<.001	<.001	.05
	11.5	<.1	.02	<.1	<.0003	.02	ND	.002	.02
	17.	.1	.008	<.1	.00008	.006	.001	<.001	.02
SG-18A	190.	<.02	<.02	.02	.0024	.005	ND	.001	.03
	.1	<.05	.01	.03	.0003	.01	.004	<.002	.7
	6.3	.8	.004	.03	<.0001	.006	ND	.002	.01
	5.6	<.1	<.02	<.1	.00012	.006	<.006	<.001	.04
SG-19	3.1	<.05	<.008	.002	.0019	.002	ND	<.001	.05
	24.	<.05	.009	.01	.0003	.02	ND	--	2.
	22.	.4	.03	.006	.0002	.009	ND	.002	.05
	23.	<.1	.004	<.1	.00009	.01	<.001	<.001	.01
SG-20	25.	<.05	.008	.007	.0002	.03	.002	<.001	.04
	21.5	.3	.01	.01	.0001	.006	ND	<.001	.04
	22.	<.1	.005	<.1	<.00003	.009	ND	.001	.03
	21.	<.1	<.02	<.1	.00008	.007	<.003	.002	.008
SG-21	8.6	<.05	.01	.03	.0003	.02	.003	.003	.1
	9.3	.2	.007	.03	<.0001	.004	ND	.003	.03
	9.	.2	.02	<.1	.0001	.01	<.006	<.001	.02

MINOR TRACE ELEMENTS - UPPER AQUIFER

WELL	Y	Sr	Rb	Br	Ge	Ga	Ti	Sc	W
Cb-2		.7	.02	.03		.003	.07	<.001	
		.8	.02	.03		<.001	.03	<.002	.01
		2.	.003	.01			.05	<.001	
		.2	.009	.01		.001	.04	<.003	
Cb-4		2.	.006	.03		.003	.08	.002	
		3.	.02	.06		<.002	.3	<.004	.02
		5.	.003	.05		.001	.2	<.001	
		1.7	.02	.003		<.003	.03	<.006	
AT-1^c String 3		2.	.01	.02			.08	.002	
		3.	.04	.02		<.001	.05	<.003	
		3.	.02	.05	<.002	<.002	.2	<.001	
		3.6							
		1.8	.02	.005		<.002	.07	<.004	
SG-1 String 2		2.	.006	.02			.03	.006	
		3.	.008	.02			.3	<.001	
		3.		.006			.2	<.007	
		3.3	.01	.009	<.002	.001	.05	<.003	
SG-6 String 3	<.001	17.	.02	.01			.05	<.003	
			.009	.01			.2		
		7.3	.003	.01			.003	<.005	
		6.	.002	.004		.002	.1	<.004	
SG-8 String 2		3.	.04	.05	.002	.002	.08	<.003	
	.01	1.	.02	.02	<.001	.003	.1	<.001	
SG-9 String 2		3.	.02	.03			.05	.009	.01
		2.	.02	.03		.001	.03	.002	
		4.	.05	.06			2.	<.001	
		2.5	.02	.02			.08	<.003	
		4.	.01	.09		.003	.08	<.005	
SG-10A		4.	.003	.02		<.002	.03	<.005	
		4.	.03	.2			.3	<.002	
		1.7	.02	.02		<.002	.08	.005	
SG-11 String 3		3.	.04	.05		<.001	.05	<.003	.02
			.02	.03			.1	<.001	.002
		1.7	.05	.007		.002	.08	.005	
SG-17 String 2		.2	.03	.2			.3	.005	.02
	<.001	.7	.009	.05	.002		.05	<.001	.003
		.1	.007	.03		.004	.06	<.004	
		.2	.008	.01	<.001	.001	.04	<.001	
SG-18A		.3	.004	.01		--	.04	.003	
		2.	.01	.008			.03	<.002	
		3.	.01	.01			.3	<.001	
		1.9	<.002	.004		<.003	<.1	<.007	
SG-19		.4	.005	.01		.002	.03	.001	
		.4	.006	.008		.001	.1	<.002	.01
		.4	.006	.02	<.002		.05	<.001	
		.4	.004	.006	.001	.001	.02	<.002	
SG-20		.7	.02	.01		<.001	.2	<.003	
		.4	.007	.03		<.001	.02	<.001	
	<.001	.4	.01	.01		.001	.02	<.001	
		.5	.008	.006		.004	.06	<.004	
SG-21		2.	.006	.02		.002	.03	.006	
		.5		.02		<.002	.04	<.001	
		1.	.02	.004		.003	.09	<.006	

MINOR TRACE ELEMENTS - UPPER AQUIFER

WELL	U	Th	Cs	I	Sb	Ag	Mo	Zr
CB-2	.03		.007 <.001 .003	.003 .001	.01 <.001	<.001	.04 .04 .009 .03	.002 .001
CB-4	.02 <.002		.01 .001 <.003	.004 .02 .004 .003	.008		.02 .04 .03	<.003
AT-1c String 3	<.001 <.001		.004 .008 .002	.002 <.001 .003 .002	.003 .002	<.003	.02 .03 .02 .02	.002
SG-1 String 2	.002	<.001	.003 .01	.006 <.001 .005 .003		.02	.02 .03 .03	<.002 .001 .001
SG-6 String 3			.004 .002	.004 <.001 .002		<.002	.003 .01 .04	<.001 .004 .003
SG-8 String 2	.007 .004		.04 .02	.02 .002	<.001	<.001	.01 .01	.003 .001
SG-9 String 2			.005 .003 .003 .002	.005 .003 .01 .003	.006 .02		.08 .02 .05 <.01 .02	.001
SG-10A			<.002 .02 <.002	<.002 .02 .002		.05	.04 .09 <.007	<.002 <.002
SG-11 String 3	.002 <.001		.01 <.001 .03	.02 .006 .002	.006 .002	.001	.01 .01 .02	.002
SG-17 String 2	<.001	<.001	.2 .02 .004 .01	.08 .004 .01 .002		<.001 <.002	.1 .02 <.02 .006	.03 .003
SG-18A			<.002	<.002 .002			.03 .01 .03 .03	-- .003 .01
SG-19	<.001	<.001	.001 .01 .002	.004 .001 .006 .002	.001	.001	.003 .008 .01 .003	.002 .009 .03 .001
SG-20	<.001	<.001	.01 .003 .002 .005	.002 .003 .002 .004		.001	.03 .006 <.008	.01 .006 .004
SG-21			.002 .02 <.002	.003 .005 .002		.003	.02 .02	.03

WATER QUALITY PARAMETERS - LOWER AQUIFER

Well	Conductivity	pH	TDS	Alpha Rad.	Beta Rad.	DOC	TOC
Cb-1	3900	8.7	2500	4	0		<1
	4000	8.7	2500	13	0		6
	3800	9.1	2200	3	0		4
	4097	8.7	2570	19	0	*	
AT-1c, String 1	1400	9.0	1200	4	41		<1
	1100	9.0	800	10	0	5	4
	1400	9.0	780	9	0		2
	1300	8.8	792			5.8	
	1415	9.0	817	18	33	*	
AT-1c, String 2	1400	8.5	890	2	0		<1
	1200	8.3	760	7	0	2	2
	1200	9.0	720	10	0		2
	1250	8.8	744			5.0	
	1329	8.7	748	8.5	24	*	
SG-1, String 1	4400	8.7	3000	23	0	4	6
	2900	8.9	1900	13	0		5
	7000	8.4	5236			11	
	8369	8.7	5747	33	0	*	
SG-6, String 1	2100	8.4	1300	4	12	7	6
	2700	9.1	1700	16	0	35	40
	2300	8.8	1542	18	4	9	
	3099	8.8	1894	6.2	33		
SG-6, String 2	1200	8.8	830	6	0		7
	1300	8.9	810	3	0		5
	630	9.3	356	1.3	0	8.4	
	2211	8.9	776	4.4	0	*	
SG-8	1800	8.8	1200	3	0		5
SG-8R	1850	9.0	1197			4	
	1350	8.6	385	4	11	35	
	1889	8.8	1167	6.6	9	*	
SG-9, String 1	1400	8.4	1000	4	0		<1
	3100	8.6	2000	6	0		8
	1400	9.0	880	6	0		4
	1700	8.6	1316			175	
	1378	8.6	1411	8.4	34	*	
SG-10	45000	8.3	42000	320	0	25	26
SG-10R	4900	8.1	2753	0	15	6.6	
	4690	8.2	2550	9.9	6	*	
SG-11, String 1	40000	8.8	39000	43	390		38
	40000	8.4	39000	460	0	26	25
	36000	8.6	39000	36	0	23	25
String 1R	20420	8.6	15870	0	70	*	
SG-11, String 2	1200	8.7	870	8	0	3	2
	1200	9.0	710	7	0		3
	1287	8.7	726	6	16	*	
SG-17, String 1	32000	8.5	28000	3	0	20	18
	29000	8.7	28000	20	0	15	17
String 1R	9600	8.6	6486			58	
	6768	8.7	4300	17	2	*	

*Samples contaminated with acetone

MAJOR CONSTITUENTS - LOWER AQUIFER

	NH_3	HCO_3	Ca	CO_3	Cl	OH	Li
Cb-1	2.1	2500	4	62	64	<.1	<.5
	3.4	2700	5	43	30	<.1	<.5
	1.2	2200	3	83	9	<.1	<.5
	2.2	2670	4	55	17	--	<.5
AT-1c, String 1	0.1	780	4	160	36	<.1	<.5
	1.0	780	4	30	4	<.1	<.5
	0.6	710	5	24	38	<.1	<.5
	3.1	748	4.8	21	4.4	--	--
	.6	738	5	30	9	--	<.5
AT-1c, String 2	0.4	420	28	7	9	<.1	<.5
	0.4	740	7	18	3	<.1	<.5
	0.6	660	6	22	3	<.1	<.5
	2.8	716	6.3	16	1	--	--
	.36	722	6	14	3	--	<.5
SG-1, String 1	4.4	2600	12	62	280	<.1	1.3
	1.7	1800	6	54	68	<.1	<.5
	9.5	3730	6.9	160	610	--	4.1
	15.5	4300	7	120	700	--	5
SG-6, String 1	6.3	820	16	12	180	<.1	<.5
	3.7	1400	2	60	131	<.1	<.5
	5.2	1430	5.4	35	19	--	<.5
	2.2	1860	7	47	50	--	<.5
SG-6, String 2	1.8	600	8	18	73	<.1	<.5
	2.5	700	5	42	48	<.1	<.5
	3.0	265	4.7	17	31	--	<.5
	.76	744	5	20	12	--	<.5
SG-8	1.8	1200	3	30	3	<.1	<.5
SG-8R	1.1	1196	5	36	10	--	<.5
	.3	880	2.8	17	4.4	--	<.5
	.95	1150	4	32	-	--	<.5
SG-9, String 1	0.1	970	19	17	28	<.1	<.5
	6.8	1700	4	26	138	<.1	1.5
	0.9	870	5	24	11	<.1	<.5
	3.1	1200	4	20	80	--	.8
	3.45	1290	5	24	98	--	.9
SG-10	197.	25000	5	1600	9800	<.1	79
SG-10R	.6	104	216	--	1370	--	.5
	3.8	287	127	--	1263	--	<.5
SG-11, String 1	--	22000	6	2000	8150	<.1	79
	91.	21000	16	1700	9800	<.1	63
	130.	23000	6	1500	8200	<.1	76
String 1R	25.5	11300	9	288	3280	--	23
SG-11, String 2	0.5	740	10	21	20	<.1	<.5
	1.2	630	10	21	9	<.1	<.5
	1.15	677	7	15	8	--	<.5
SG-17, String 1	100.	18000	11	720	6900	<.1	43
	150.	17000	9	1000	6200	<.1	58
String 1R	16.8	4740	8.9	130	1064	--	5
	12.0	3260	10	108	640	--	2.6

MAJOR CONSTITUENTS - LOWER AQUIFER

	Mg	NO_3	PO_4	K	Na	SiO_2	SO_4
Cb-1	4 4 3 3	0.5 0.9 2.9 .02	<.1 <.1 <.1 .04	9 14 4 5	1100 1100 1000 1120	12 15 13 17	<4 12 <4 10
AT-1c, String 1	4 4 3 3.6 3	<.1 <.1 0.2 .1 .08	<.1 <.1 <.1 .08 .03	-- 7 8 6.6 10	520 320 330 327 340	12 10 6 11 12	96 17 <4 25 17
AT-1c, String 2	29 8 6 5 4	1.0 <.1 0.2 <.04 .22	<.1 <.1 <.1 .02 .03	6 3 3 4.2 2	230 310 290 304 310	16 19 13 13 14	350 14 33 25 22
SG-1, String 1	15 8 11.6 10	<.1 1.8 .10 .28	<.1 <.1 .02 .02	12 5 20 20	1200 780 2130 2320	13 11 11 17	150 <4 316 313
SG-6, String 1	9 3 3.4 4	1.6 3.4 .96 .24	<.1 <.1 .07 .07	32 13 7.3 6	450 770 660 800	5 3 9 15	180 16 82 26
SG-6, String 2	16 7 1.9 4	<.1 2.9 <.04 .16	<.1 <.1 .04 <.02	11 5 2.5 2	290 330 143 320	2 4 2 11	110 <4 16 17
SG-8	3	0.2	<.1	1	490	13	24
SG-8R	3 1.5 3	.04 <.04 <.02	.06 .24 .07	1.8 3.1 2	505 358 515	5 21 14	29 28 <4
SG-9, String 1	3 4 3 2.9 3	<.1 <.1 0.2 .12 .24	<.1 <.1 <.1 <.02 .02	5 7 2 3.7 4	410 830 370 348 375	13 12 14 13 17	67 37 <4 12 12
SG-10.	10	0.5	0.7	122	17000	21	25
SG-10R	111 110	.2 <.02	.05 .01	11.3 10	640 650	2 11	329 211
SG-11, String 1	14 10 4	<.1 0.6 0.3	<.1 <.1 <.1	125 120 122	16000 16000 16000	24 38 21	2 90 <4
String 1R	8	.06	.24	34	6140	19	20
SG-11, String 2	13 10 6	<.1 <.1 .34	<.1 <.1 <.02	5 2 3	330 280 295	10 13 11	82 38 29
SG-17, String 1	13 7	0.5 0.2	<.1 <.1	95 91	11000 11000	24 20	120 <4
String 1R	7.1 7	.12 <.02	<.02 .04	18.6 11	2680 1800	17 17	41 7

IMPORTANT TRACE ELEMENTS - LOWER AQUIFER

	Al	As	Ba	Be	B	Cd	Cr	Co	Cu
CL-1	.05 .08 1.0 .6	.002 .008 .002 .004	.08 .3 .2 .4	ND ND <.001 .001	.7 .9 .8 1.	ND ND ND .01	.006 <.01 <.01 .004	.01 .01 <.001 .004	.09 .03 .02 .03
AT-1c, String 1	.9 .08 .05 1.	.03 .003 .005 .003 .020	.04 .3 .04 .1	<.001 ND ND ND	1.1 .43 .6 .05	ND ND ND ND	.003 <.01 <.01 .01	.006 .004 <.001 <.009	.1 .03 .02 .2
AT-1c, String 2	.5 .4 .1 .04	.05 .01 .02 .03 .007	.1 .2 .2 .1	.002 ND ND ND	1.4 .64 .8 .1	ND ND ND ND	.005 <.01 <.01 .009	.003 .001 ND <.007	.03 .02 .007 .004
SG-1, String 1	-- .5 .09 .06	.005 .004 .03 .06	.09 .1 .04 .02	<.001 ND ND ND	12 .7 10 --	ND ND ND ND	<.01 <.01 .003 .002	<.001 <.001 <.006 <.01	.09 .03 .09 .02
SG-6, String 1	.5 .09 .005 .1	.003 .01 .003 .009	.06 .02 .1 .2	ND ND ND .001	.65 .2 .2 .7	ND ND ND ND	<.01 <.01 .003 .005	<.001 <.001 <.001 <.002	.03 .005 .01 .04
SG-6, String 2	-- .1 .02 .03	.009 <.002 .002 .001	.06 .03 .07 .02	ND ND ND ND	.70 .4 .1 .3	ND ND ND ND	<.01 <.01 .01 .007	<.001 <.001 <.005 .006	.01 .003 .03 .01
SG-8	.01	.02	.4	ND	1.1	ND	<.01	ND	.02
SG-8R	.09 2 .3	.006 .03 .030	.1 .4 .5	<.001 ND <.001	.08 .05 .05	ND ND ND	.007 .01 .009	<.002 <.001 <.004	.03 .01
SG-9, String 1	.4 .05 .2 .1 .07	.02 .006 .005 .016 .020	.08 .08 .1 .08 .2	.001 ND ND ND <.001	4.9 4.3 1.4 .3 .8	.1 ND ND ND ND	.006 <.01 <.01 .02 .007	.002 .002 ND <.009 .003	.03 .009 .004 .02 .02
SG-10	.3	--	5	<.001	405	ND	<.01	ND	.9
SG-10R	.03 .03	.006 .010	.09 .09	ND <.001	.6 .6	<.01 ND	.01 .02	.003 .02	.04 .02
SG-11, String 1 String 1R	0.4 0.04 .08 .04	.03 .2 .1 .040	5 2 2 6	.002 ND <.001 .001	315 305 310 --	ND ND <.007 ND	.007 <.01 <.01 .007	.03 <.009 .02 <.02	0.2 .2 .02 .1
SG-11, String 2	.08 .4 .07	.05 .06 .006	.09 .09 .1	ND ND ND	1.1 2.7 .3	ND ND ND	<.01 <.01 .02	<.001 <.001 <.01	.01 .004 .009
SG-17, String 1 String 1R	.2 .3 .002 .09	.09 .04 .009 .020	8 3 .3 .7	.001 .001 ND <.001	200 7 9	ND ND ND ND	<.01 <.01 .003 .005	<.02 <.008 <.002 .002	.04 .2 .008 .03

IMPORTANT TRACE ELEMENTS - LOWER AQUIFER

	F	Fe	Pb	Mn	Hg	Ni	Se	V	Zn
Cb-1	16	.3	<.008	.2	--	.009	ND	.002	.04
	28	<.05	.02	.002	.0001	.06	.004	.004	.09
	23	.4	.02	.1	<.0001	.008	ND	.001	.03
	28	<.1	.008	<.1	.00007	--	<.002	<.001	.01
AT-1c, String 1	10	.2	.02	.06	.0019	.02	ND	.003	.2
	19	<.05	.01	.04	.0001	<.001	.002	<.001	.7
	17	<.05	.02	.02	<.0001	.01	ND	<.001	.005
	18	.3		<.1					
	20	6	.1	.1	.00004	.02	<.004	.001	.04
AT-1c, String 2	9	.18	.03	.2	.0009	.006	ND	.002	.05
	16	<.05	.02	.3	.0004	<.001	.003	.001	.05
	17	<.05	.008	.1	<.0001	.004	ND	<.001	.02
	15.5	.1		<.1					
	17	.1	<.01	<.1	.00007	.003	<.002	<.001	.01
SG-1, String 1	21	<.05	.02	.1	.0003	.02	--	<.001	.1
	20	.1	.01	.1	.0001	.004	ND	<.001	.2
	28	<.1	<.01	.1	.00003	--	ND	<.006	.03
	25	<.1	<.03	.1	.00009	--	<.008	<.006	.009
SG-6, String 1	11	<.05	.01	.2	.0027	.02	ND	.002	.03
	20	.2	.006	.03	<.0001	.005	ND	.002	.06
	16.4	<.1	<.005	.1	<.00003	.005	ND	.001	.01
	22	<.1	<.004	.1	.00008	--	<.001	.001	.02
SG-6, String 2	12	<.05	.01	.02	.0016	.006	ND	<.001	--
	15	<.05	.003	.06	<.0001	.008	.001	<.001	.2
	6.5	.1	<.02	<.1	<.00003	.007	ND	.002	.05
	17	.1	.01	<.1	.00015	.01	<.004	<.001	
SG-8	26	<.05	.009	.05	.0001	.006	--	.001	.5
SG-8R	14	.3	.05	<.1		.01	<.001	<.001	.03
	16.5	1.2	<.01	<.1	<.00003	.01	ND	.001	.02
	22	<.1	<.008	<.1	.00006	.01	<.002	<.001	.02
SG-9, String 1	15	.68	.01	.09	--	.003	.005	.002	1
	25	<.05	.01	--	.0002	--	ND	.004	.05
	19	.9	<.004	.03	<.001	.004	ND	<.001	.01
	21	<.1	<.01	.1	<.00003	.02	ND	.003	.07
	20	.2	<.006	<.1	.00011	--	.002	<.003	.02
SG-10	47	3.1	.04	.1	.0001	--	--	.1	.03
SG-10R	4.4	<.1	.004	.2	.0002	--	<.003	.002	.02
	4.	2.4	<.01	.6	.00006	--	<.003	.001	.09
SG-11, String 1	48	2.3	.03	.07	.0026	--	ND	.02	.03
	46	<.05	.4	.04	.0002	--	.01	.1	.05
	42	7.7	.04	.04	.002	--	.006	<.05	.01
String 1R	26	1.8	<.03	.1	.00023	---	ND	.03	.03
SG-11, String 2	14	<.05	.04	.05	.0003	.04	.004	.002	4
	14	.8	.004	.05	.0001	.006	ND	.002	.06
	17	.1	.03	<.1	.0001	.02	ND	.001	.01
SG-17, String 1	34	1.5	.07	.09	.0001	--	.02	.03	.05
	37	7.9	.07	.1	.0001	--	.006	<.04	.02
String 1R	22	<.1	.005	.1	<.0001	--	<.002	.007	.005
	21	<.1	.02	.1	.00009	--	<.003	<.001	.005

APPENDIX VI.12

MINOR TRACE ELEMENTS - LOWER AQUIFER

	Y	Sr	Rb	Br	Ge	Ga	Ti	Sc	W
[illegible]-1	<.002 <.001	.4 .6 .2 .4	.01 .04 .01 .02	.03 .01 .03 .01	<.001 <.002	.003 <.001 .001	.05 .2 .01 .05	<.001 <.003 <.001 <.003	
[illegible]-1c String 1	<.001	.4 1 0.5 .7 .3	.1 .04 .01 .04	.05 .01 .01 .01	.002 <.001	.002 <.001 <.003	.08 .08 .01 .01	.002 <.001 <.001 <.007	.02 .004
[illegible]T-1c String 2	<.001	5. 1. 2. .9 .6	.05 .02 .009 .007	.03 .008 .01 .004		<.001 <.003	.1 .03 .09 .03	.003 .002 <.001 <.001	.05
SG-1 String 1	<.02	.9 1 .4 .2	.1 .006 .03 .01	.2 .05 .3 .08	<.02	.002 .002 .01	.006 .05 .2 .08	.002 <.001 <.002 <.01	.01 <.02
SG-6 String 1	.01	.7 .1 .2 .2	.09 .05 .01 .009	.05 .1 .009 .01	<.003 <.001	.001 <.001 .001	.05 .02 .01 1.	.006 <.001 <.001 <.004	.008
SG-6 String 2		.7 .6 .3 .3	.04 .02 .04 .005	.05 .05 .03 .003		<.001 <.003 .002	.05 .04 .04 .03	.003 <.001 <.002 <.005	
SG-8	<.001	.8	.006			.002	.01	.002	.01
SG-8R	<.001	.4 .3 .6	.04 .01 .01	.006 .02 .006	<.002	.001 .002	.4 .3 .02	<.001 <.004 <.003	<.002
SG-9 String 1	.001	2. .2 .3 .4 .2	.05 .01 .01 .03 .006	.03 .2 .03 .05 .03	<.001	.003 .002 .003 .001	.1 .3 .01 .04 .04	.002 .002 <.001 <.003 <.002	.01 .008
SG-10	<.02	2.	.4	10	.05	<.03	.03	.01	
SG-10R	<.001 <.001	10.3 8.7	.05 .04	.1 .07	.02	<.001 .007	.3 .2	<.002 <.004	
SG-11 String 1 String 1R	.03 <.01 <.008 <.03	3. 1. .8 1.2	.04 .9 .04 .2	.8 8 .6	.05 <.007	.02 <.03 <.01 <.007	.2 .3 .2 .1	.01 <.007 <.004 .01	.02
SG-11 String 2	.01	2. 1. .4	.05 .02 .05	.03 .01 .006		<.001 .005	.03 .06 <.08	.004 <.002 <.006	.009
SG-17 String 1 String 1R	<.03 <.003	6. 2. .4 .6	.4 .3 .02 .01	3. 7. .3 .3	.02 <.04	<.06 <.03 <.001 <.004	1. .1 .03 .2	<.008 <.01 <.002 <.008	.04

MINOR TRACE ELEMENTS - LOWER AQUIFER

	U	Th	Cs	I	Sb	Ag	Mo	Zr
Cb-1			.002 .009 .02 .01	.002 .004 .008 .002			.02 .02 .005	.004 .003 .002
AT-1c String 1	.002 <.001		.07 .04 .003 .01	.006 .003 .002	.03 .006 <.001 .04		.07 .03 <.008	.004 <.001 .003
AT-1c String 2			.02 .03 .002 .008	.01 .003 <.001 .002	.002	<.002	.1 .08 .02 .008	.01 .002
SG-1 String 1	.02		.1 .02 .07 .01	.06 .01 .06 .06	.007 <.01 <.01		.1 .02 <.02	.08 <.001 .009 .01
SG-6 String 1	<.001	<.001	.01 <.001 <.001 .003	.02 .04 .002 .001	.006 .004		.01 .1 .01 .02	.002 <.001
SG-6 String 2	.02		.02 .005 .005	.02 .004 .01 .002	.002 <.004	<.002	.1 .06 .03 .02	<.003 .002
SG-8	.001		.01	.003			.008	.002
SG-8R	.003		.04 .001 <.002	.001 <.001 .001	<.001	<.001	.03 <.008 <.004	.001 <.002 .007
SG-9 String 1			.01 .05 .005 .02 <.003	.01 .1 .003 .008 .003	.009 .01 <.001	.009	.07 .04 .02 .03 .02	.005 <.001 .004 .006
SG-10	.008		3	2		.02	.08	.4
SG-10R			.02 .03	.002 .005	<.02 .01	<.01	<.007 .008	.001 .002
SG-11 String 1 String 1R	.006		.04 4 .1 .04	.5 3 2. .08	.008 .08 < .01	.02 <.01	.01 .1 .03	.9 .6 .2 .1
SG-11 String 2			.01 .01 .04	.02 .006	.004		.2 .08 <.05	.009
SG-17 String 1 String 1R	<.003		2. 1. .07 .005	2. 2. .2 .05	.04 .002	<.01	.04 .02 .02	.3 .3 .008 .003